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THE UTILIZATION OF THE BEHAVIORAL SCIENCES
IN LONG RANGE FORECASTING AND POLICY PLANNING

Volume II of II

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August 1976

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Why War: A Mathematical Systems Approach*

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The Technical Reports which comprise this volume provide detailed documentation of the technical work accomplished under this contract (ARPA Contract No. 3527-A1, DAHC 15 73 C 0197). These reports were written throughout the period of the contract and were originally submitted as appendices to the various Semi-Annual Technical Reports. Substantively these reports treat the range of topics dealt with under this contract including the role of forecasting in foreign policy planning, an
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evaluation of various analytic methods used in forecasting and policy planning, an evaluation of the utility of some of the major empirical studies of international behavior for forecasting and policy planning, and extensive treatments of the various components of the Saudi Arabian planning simulation.

INTRODUCTION

This introduction serves two major purposes--it describes the broad thrust of our research efforts and it provides a brief sketch of what we want our explanatory theory to look like. The introduction should provide some clues as to where we hope this first step will take us, and how we propose to get there.

The search for causes of war has been the major concern of international relations scholars for centuries. One suspects that wars are caused by all manner of things. There might be truly belligerent nations which engage in conflicts to satiate some primordal blood need. Imperialist design might account for what we can war, as might manifest destiny or the glory of some heavenly kingdom. It might be that nations systematically lie about their intentions, i.e., feign friendly behavior while awaiting for the right moment to strike. Our interest is in why wars come about. It might be that ideological differences make it impossible for nations to interpret actions which were intended as friendly in any but hostile terms, or that nations make mistakes about what other nations actually do, i.e., nations go to war due to factual or perceptual errors, or that nations are simply wrong in their judgements as to how other nations will respond to their actions. We can see that these last three sorts of causes might lead to war when no nation wishes it. It is this sort of political phenomenon that we find puzzling and wish to address.

Our concern is with wars that are accidental or in a sense unwanted. In order to deal with our three reasons for unwanted war we are faced with the task of constructing a language in which we can talk about international relations. This language and its concepts serves as our basis for talking about the causes of accidental war. In this basic language we specify what a nation looks like, what national behavior is, and how a nation generates behavior. Before we can talk about accidental war, we must have a fairly detailed and complete picture or theory of international relations. This paper serves as a first step in developing that language. Specifically in the work done here we develop the concept of state (used here in a technical sense, to be explained below, not to be confused with a nation) and our notion of a state transition function. What we have done is to develop a set of computer simulations that concern themselves with how a nation's orientation or outlook changes as a function of the behavior it receives from another nation. Thus this paper will not directly address itself to the concept of accidental war, but it will lay the ground work for such a discussion.

While we don't know exactly what this language will look like when it is complete, we do have some preferences about what form it should take. One of the major tennants of standard philosophies of science, e.g., Tarski (1941) or Hempel and Oppenheim (1948) is that conclusions of a theory are strictly deducible from antecedent conditions. A current illustration of a working social scientist who has

adopted such a framework for his own efforts is Allen Newell.

> Production systems (Newell's theories) like other programming systems and mathematical theories, are complete in the sense of producing theoretical consequences that are deducable from the theory. (Newell 1973a: 517)

Similar to Newell, in meeting this aspect of scientific respectability we choose the language of mathematical systems theory with which to theorize about the phenomena of war.

A deductive language is not our only preference. In his articles dealing with what he calls production systems, Newell (1973a, 1973b) makes an argument about the advantages of building what he calls "complete processing models". In his paper, "You Can't Play 20 Questions with Nature and Win", Newell makes a very persuasive argument that a binary approach to social knowledge (i.e., hypothesis testing) is not only not necessarily the best manner in which to proceed. Given current rates of science- doing or even conceivable rates of science-doing such proceedures will not yield full blown theories. In place of the rather mindless plodding of the binary approach, Newell suggests models which completely model the phenomena of interest. Without analyzing the merits of Newell's allegations we assert that it is toward this sort of completeness that our efforts are aimed. This is the reason why we spend alot of time developing a theoretical language prior to beginning our discussion of accidental war. If we can manage to construct a complete processing model

we will have a theoretical structure that will allow us to treat any aspect of international behavior -- not just accidental war. We have chosen to take a more round-about manner in which to address the notion of unwanted war. If we can succeed in building an acceptable language, we will be left with much more than a handful of hypotheses. We realize that the path we have chosen has a greater chance of failure than the hypothesis testing route, but the possible payoffs seem to outweigh the potential problems.

Introduction to Systems Theory

Allow us to motivate the systems theoretic approach to mathematical modeling.

Imagine one standard Large Midwestern University (L.M.U.) athlete who happens, *in his spare time*, to practice science. Our athlete, Maurice, has noticed that when he showers there seems to be some relationship between the location of the shower-control handle and the temperature of the water coming from the nozzel.

Insert Figure I Here

Most atheletes at L.M.U. don't go any further than to notice this gross relationship, fiddle with the control-handle until the shower temperature is acceptable and that's that.

But Maurice is a part-time intellectual and therefore has signed up for a political science class. Since it is an L.M.U. political science class Maurice is going to get some practical experience at doing research science, i.e., he is charged with the task of choosing a dependent variable and ascertaining how it is related to some independent variable or variables. Because the political science instructor has been through the trials of the late 60's and the riots of the early 70's the instructor realizes the importance of making his scientific discipline relevant to the student. This being the case he agrees, after several personal appearances by the athlete at the instructor's office hours (11:00 to 11:15 M-F, except Fridays, Tuesdays, Mondays, and every second Wednesday) that the "shower temperature - control handle" problem will be an acceptable research topic. Maurice does a case study. His null hypothesis is:

> Ho: There is no relationship between the location of the control handle and the temperature of the shower.

and his alternative, or research hypothesis is:

> H_1: There is some relationship between the location of the control handle and the temperature of the shower.

(Maurice knows two tailed tests are less restrictive than one tailed.)

Next day, after practice, Maurice marches to his shower armed with pencil, paper, and high hopes. He sets the

control-handle to the 'cold' location and immediately begins to empathize with those who bemoan the troubles of data collection. The instructor, who has by now developed enormous enthusiasm for Maurice's original and rigorous design, assigns to Maurice his own personal work-study slave to assist in data collection. Well, leaving out much detail, Maurice discovers that there is perfect two way association between temperature of the shower and the location of the control-handle! Hot dog -- Maurice is elated, the instructor is pleased (he goes so far as to suggest that with a little polish the ensuing paper on the "Shower Project" will be publishable) etc... But alas, a more senior member of the faculty points out that with an "n" of one we can't be too sure of our results-- so Maurice, who has by now given up athletics for science, is off to survey the entire population of showers at L.M.U. NSF is good enough to spot a hot prospect when they see one and award a grant without which Maurice could never have collected data on women's and dorm showers. The candidate for a scientific law, unearthed by the pilot "Shower Study of 1972" holds and Maurice, now a Ph.D. candidate, has tremendous prospects for a career in political science. (He is in comparative, currently working on a proposal that would allow him to sample showers from the five nations of the classic Almond and Verba study to shed light on the cultural bias hypothesis.)

But alas, a new athlete at L.M U., coming up through the same political sciencey ranks as Maurice, has been encouraged to replicate Maurice's L.M.U. study and finds that only some showers behave as Maurice has claimed, i.e., one group of showers in the men's gym always yield cold showers regardless of the control-handle location. Fortunately this second student has had an extensive background in mathematics and systems engineering and can come up with a state-space explanation of the observations:

INPUTS	STATE	OUTPUTS
cold	1	cold
warm	1	warm
hot	1	hot
cold	2	cold
warm	2	cold
hot	2	cold

Maurice, of course, is insulated from this new explanation's nasty implications, by now himself being a tenured individual at a large midwest university and our new athlete is hailed as one of the 'coming breed' math modelers. (When queried, the crew down at the gym mentioned that Maurice and the upstart are both right, i.e., back when Maurice did his study all showers were hooked up to the hot water heater, but during the energy crisis some were put on a 'cold only' line to save oil.)

The point is that results of statistical input-output explorations might result in confusing results, and that the notion of state can untangle apparent unintelligi-

bility.

Symbolically:

I	O
1	1
1	2

$\sim(I \rightarrow O)$

I	S	O
1	1	1
1	2	2

$(I \times S \rightarrow O)$

While input does not imply output, input plus state does. This is formalized in the appendix.

Systems Theory -- A More Formal View

Systems theory is a set theoretic structure. Essentially it is the delineation of sets called objects, e.g., $\{X^1, X^2, X^3 \ldots X^\alpha\}$ and the relations between those objects, i.e., the configurations of the object sets which obtain. Very generally an object is a set X^j which consists of a number of elements, $(x_1^j, x_2^j, \ldots x_n^j)$ that are referred to as the appearances of the object. An appearance can be thought of as "the value of the variable, x^j". A system is then a formal mathematical relation defined on such object sets, i.e., $S \subseteq X^1 \times X^2 \times \ldots \times X^\alpha$. An appearance of the system is then an ordered collection

$$S^1 = (x^1, x^2, \ldots x^\alpha)$$

where:

$$x_i^1 \in X^1$$
$$x_i^2 \in X^2$$
$$\vdots$$
$$x_i^\alpha \in X^\alpha$$

In the most general case S would have the cross product of the appearances of the objects as possible appearances of the system (elements $S^1 \ldots . S^n$ of the set S)

A simple example of such a cross product is:

$$S \subseteq X^1 \times X^2 \text{ where } X^1 = \{1,2\} \text{ and } X^2 = \{1,2,3\}$$

Appearances of this system are:

$S^1 = \{1,1\}$
$S^2 = \{1,2\}$
$S^3 = \{1,3\}$
$S^4 = \{2,1\}$
$S^5 = \{2,2\}$
$S^6 = \{2,3\}$

If we graph the objects of this system we see that all points of the graph are appearances of the system:

Insert Figure II Here

Obviously if there are many objects, or an object has many elements, or both, the appearances of the system might encompass an enormous variety of behavior. (Try writing the possible appearances of a system consisting of three objects of ten appearances each if this is not clear.) Such collections of behavior can easily become as unwieldly as reality itself if some parsimony is not at hand. Hopefully the entire cross product will not obtain and the theorist will need concern himself with only a proper subset of the cross product. Systems theory gets interesting when the theorist develops rules for moving from one appearance to another. Our theorizing about war will be

in this systems theoretic style. We will define the objects of the system and specify the rules for moving from one appearance of the system to another. Behavior of these posited systems will be observed and new systems, better satisfying our intuitions as to the phenomena of war will be developed and observed.

In so that we might satisfy our desire to construct a deductive theory, capable of being imbedded in a planning scheme, amenable to control theory, we develop the basic building blocks. We construct our theoretical analog to nations and the analog to the international arena in which they perform. We build 'nations' that are capable of action in the 'world' and observe their behavior. After observation we sophisticate our entities so as to preserve more of the behavior that we find in the real world. Beyond the scope of the current effort is an application of control theory. We are simply designing a model of the international system which when satisfactorily developed will be amenable to the techniques of control.

<u>The Big Picture</u>

Remembering the central position of the concept "state" to our systems approach we model nations as machines which behave according to the following scheme:

Outputs = f(inputs, state)

rather than the more common, e.g., Rummel (1971):

Outputs = f(inputs)

We are modeling nations as dynamical systems. Intuitively

one would expect a dynamic system to have some way of addressing the question of time and here our intuitions do not lead us astray. Dynamical systems are systems that are parameterized by time. They display two functions.* The first function describes how the state of the system evolves over time while the second defines the functional relationship between (input, state) and output. Allow us to motivate what we understand as the 'state' of a nation in our approach to theorizing about inter-nation behavior. Fundamentally, we are predicating our theory on the proposition that differences with respect to degree of imperialism, wealth, militarism, etc... coupled with specific behavioral inputs can lead to differences in behavioral outputs. To illustrate this imagine that a world is made up of one dimension, a capitalist--communist dimension. Considering the behavior of only two nations, let us assume that our nations are identical except for their position on this one dimension. The first nation is located near the capitalist end of the dimension; the second near the communist end. Now suppose both nations receive the same input, namely that in a third nation at the capitalist end of the dimension, a workers rebellion is taking place. We would expect that the nation at the capitalist position will behave very differently from the nation having the communist position. Our notion of the state of a nation is exactly this -- a nation's position in a political space is the nation's state.

* see Figure III for an illustration of a function.

Insert Figure III Here

As was noted for our approach to satisfy the properties of dynamical systems we must specify two functions. There are two functions which form what we call the big picture or a complete, in the Newell sense, theory of international behavior. A nation will at any time, t_0, simultaneously exhibit locations in two spaces. First there will be some behavior space location which corresponds directly to behavior as recorded in one of the 'events' data sets. Here behavior is recorded much as temperature was recorded in our shower example. Secondly there is some location in state space. We recall that in the shower example this amounted to either being hooked up to the hot water or not being hooked up to the hot water. These two locations serve as inputs to our two functions as is illustrated in Figure IV.

Insert Figure IV Here

Clearly these two outputs from nation 2 serve as inputs for nation 1 in the next slice of history and so the theory iterates through time. That is the big picture of a theory of international relations modeled dynamically. It can serve as a skeleton upon which future theoretic and empirical efforts can be hung.

Now that we have laid out our approach, we will discuss some assumptions we make about our nations.

Our most fundamental assumption about nations is that they are purposive systems.

At first glance the notion of a nation as a teleological system doesn't seem that unique. When we talk about the behavior of nations in ordinary (as opposed to technical) language terms we constantly make reference to teleological concepts, e.g., national interest or national goals. Consider a statement like the following: The Arabs cut-off our oil supply in order to influence our position on the resolution of the Middle East conflict. We are attributing to the oil producing Arab nations, goals (a preferred resolution of the Middle East conflict) and interpreting their behavior (the oil embargo) as an attempt to realize those goals. On the other hand, when we start to theorize about international relations in a scientific manner we do so in a language filled with notions of social forces* and correlates of war.

There are two points to be made in relation to nations as goal seeking systems: 1) It is scientifically respectable to talk about purposive systems; and 2) Not only is it respectable, it is also fruitful to think theoretically about nations in terms of teleological systems. Social

*Rummel's (1971:48) Status - Field theory axiom 4: "Between nation attribute distances at a particular time are social forces determining dyadic behavior at that time."

scientists still carry some of the scars that were left from the slaying of the structural--functional dragon by the Ophilosophers of science. Ernest Nagel (1956) left Merton's structural--functional formulation of society in ruins, and nobody can understand Parsons. General Systems Theory embraced the notion of telos, but the version of GST practiced in international relations strips away the heart of the formulation, leaving only an empty input--output shell with which to work. Many scholars in IR talk about adaptation, but one has the feeling that most of them really aren't quite sure about it, since once they leave the broad brush approach of verbal theorizing and start getting explicit, it's back to the old input--output black box formulation of the nation. If one looks around at psychology, one finds a very different picture of the nature of the individual than was popular in the hey-days of behaviorism. Purposive systems are respectable! As Miller, Galanter, and Pribram noted in 1960: "Once a teleological mechanism could be built out of metal and glass psychologists recognized that it was scientifically respectable to admit that they had known it all along." (Miller, et. al. 1960:43) The notion of goal seeking is central to Newell and Simon's work dealing with computer simulations of human thinking and problem solving. (Newell and Simon 1972) Norbert Weiner (1961) has shown that one does not need to ascribe vital forces to an entity to call it purposive. The traditional mechanistic conceptions of

behavior that we in international relations seem so comfortable with (in our theoretical work) is not incompatible with the notions of goal seeking.

Using this notion of the nation as a goal directed system, the behavior of a nation can be interpreted as an attempt to steer or control (Deutsch 1966) the environment toward some goal state. Our nations receive inputs from the environment (the behavior of other nations) and generates outputs (other behaviors) that are intended to control the behavior of the other nations in the system. We find it reasonable to suppose that foreign policy behavior is a function of two sorts of variables. The first is internal or domestic behavior and the second is foreign policy behavior exhibited by other countries. Thus we are firm believers in Rosenau's (1967) bridges. While we are firm believers in the bridges, in the work presented here domestic influences on foreign policy are summarized by what we call the state of the nation. By treating the domestic influence as a single element in our model we are not saying that it is not important, rather that it is simpler to use the state notion than to construct a complex process specification for the influence.

Another property of our nations that will strike some as unrealistic is our assumption that all nations are talked about as unitary actors, i.e., as if they were single individuals. We do not mean to imply that this

is an all together acceptable formulation. Rather it absolves us of having to deal with a much messier world. The simpler our world is the easier it is to talk and think about. Hopefully we will be able, at some later date to generalize our approach to more fully reflect organizational/ coordination concerns.

Another assumption is that all nations have infinite capabilities and resources. By using this assumption we do not have to concern ourselves with the relationship between development and behavior, or with wars with their roots at the competition for scarce resources. Again it is not that these factors are not important -- just that their absence buys us a degree of conceptual simplicity.

Our final assumption is that all nations strictly prefer peace to war. No nation purposively plans a war -- war is not the "Clausewitzian" extension of politics in our world. The only kinds of wars nations in our world find themselves engaged in are the types of wars where there is no purposive aggression. A nations behavior may be interpreted as aggressive and threatening, but that perception is a misperception of the sending nation's behavior. The classic example of an unwanted war is World War I. (Cf., Holsti 1965; Zinnes 1968, among others) The generally accepted interpretation of the 1914 Crisis is that of a situation where misperceptions and paranoia ran high. Later in this paper we will attempt to fully specify the role of misperceptions in our world.

Up to this point we have primarily described (or ascribed) the characteristics of our nations. We will now lay out our notions of what these nations look like. Now our nations weren't born yesterday -- they have some idea where the other nations are headed, and how they react to influence attempts. In our system these properties of the nations are summarized in conceptual forecasting models. All nations have expectations of all other nation's behavior. These expectations are expressed in these models. Nations use these models to predict how other nations will react to influence attempts. Before a nation behaves, it thinks it has a good idea of how another nation will behave. Two simple models that we will discuss in detail later can serve as useful examples: the walk-a-mile and the force models. The walk-a-mile model 'says' that if I move toward him, he will come toward me. The force model states that the only way that I can get him to move toward me is to move away from him. i.e., I have to force him toward me by showing him how strong and mean I am. Holsti's (1962) analysis of the cognitive image of John Foster Dulles very nicely fits into our conception of a nation's model. The model which Dulles used to interpret and predict Soviet behavior is called by Holsti the "bad faith model". When the Soviets were "negative" Dulles interpreted them as strong. On the other hand when the Soviets were sending "positive" behavior Dulles inter-

preted the Soviets as weak. The Soviet Union, from the perspective of Dulles, was always bad -- independently of the behavior it was sending. Interpreted in our framework, Dulles' "bad faith" image of the Soviet Union meshes with our notion of a model to predict or forecast behavior, and our notion of the state of a nation.

The forecasting model serves as a basis for predicting or forecasting the behavior of another nation as a function of the behavior it receives. The goals of a nation specify what sorts of responses are desirable.

At first glance it would seem that much of our work bears a strong resemblence to Rummel's status--field theory (Rummel 1971). While some of the words we use are spelled the same as Rummel's, the meaning that we attach to them and the thrust of our inquiry are very much different. The prime differences between our work and the DON project center around two point: 1) dynamic versus static systems; and 2) the functional relationship between inputs and outputs. Status--field theory is a static system and does not change with time. While it is possible to generate predictions over time with a static system, that can only be accomplished by collecting data for each time period to be predicted. Formally the system itself is static. On

the other hand our system is parameterized by time. Functions are specified for moving the system from one appearance to another. It is closed in the sense that once the functions for our system are specified, the system can generate a time series with no further input. The second difference between the DON and our efforts concerns the functional relationship between inputs and outputs. The DON strategy is based upon the belief that outputs (behavior) are a linear combination of inputs (status dimensions), i.e., outputs= f(inputs). Our approach is that the behavior of a nation is a function of inputs and state, i.e., outputs = f(inputs,state). The "shower example" illustrates our arguments about the differences between these two approaches, and our above discussion of the effects of state on national behavior illustrates out interpretation of state for international relations. Thus while we both use some of the same words, there are fundamental differences between our efforts and the DON project.

<u>The Little Picture: Evolution in State Space for Two Nations</u>

We recall from our "Big Picture" above that modeling inter-nation behavior as a dynamical system commits one to the specification of two kinds of functions. We don't do this. Rather we choose to focus our modeling efforts on a subset of these problems, the function which takes a nation from one location in state space to another. Given this as our task we might ask that a reasonable strategy for the completion of this task be presented. With respect to

physiological-psychology we can look to recent work by Allen Newell for guidance. In this work Newell took as empirical datum to be explained a well known set of psychological experimental results, the Sternberg paradigm. He developed a machine that exhibited behavior matching that of the human subjects pointing out:

> We have now developed a theory of the simple Sternberg binary classification task that has modest standing. It should be possible to apply it to the experiments discussed in this symposium that make use of similar task situations. (Newell 1973a: 506)

The Newell approach becomes

1) specify a class of behavior to be examined

2) develop a machine that actually exhibits this behavior

3) employ this model to:

   i. better understand the empirical setting
   ii. assess existing theory in the area
   iii. control the environment

We would like to be in position to follow this recipe of science with respect to international relations. As luck would have it this is currently an unattainable goal. Put crudely there is no existing body of empirical findings with respect to location in a state space. While it remains that popular rhetoric includes many charges of "expansionist", "imperialist", "militarist", "facist" there is no handbook assigning scores along such dimensions to the nations of our world. This being the case we moved

another step back, i.e. develop machines which begin to satisfy their intuitions as to how nations "do" or "would" evolve in this state space. One more time, to avoid ambiguity, we are not doing the whole theory, but, rather we are matching our intuitions as to what reasonable behavior in state space is with machines that we build in a simulation setting. We work on only one of the machines so here we go:

Insert Figure V here

We will model the process as a complete, general dynamical system. This entails that all objects of our system are parameterized by the same time set. (see appendix for a more formal treatment of dynamical systems.) Very generally our systems are:

$$S \subseteq X^t \times M^t \times N^t$$

where:

X^t = state space
M^t = model set
N^t = nation label set

Some discussion of each set seems to be in order here.

X^t; State Space:

This is the same space that was discussed in the above section. We define this space as a vector space. (See appendix for the formalization of vector space.) Doing this, while not crucial to the versimilitude of this primitive work, facilitates the later incorporation of mathematical optimization techniques. Dimensions of this

space might reasonably be interpreted as: expansionist--isolationist; pro-east--pro-west; belligerant -- pacifistic; chauvinist-- internationalist... sorts of contina. Assuming "n" dimensions in our space, a nation's location in space would be an n-tuple vector from X^t, the order of which has meaning.

M^t; model set

It just so happens that for a nation to behave in this or any simulation of an international system it must have an algorithm defining its behavior. We feel that this corresponds to a nation's real world "image" of the international system. Obviously such images can be very *simple:* Everybody hates me. Very uncertain: I really don't know what is happening. Or very sophisticated with lots of face validity. Our models will be of the form:

$$\underline{\dot{x}} \times n = f(\underline{u}, \underline{x} \times n) \qquad \text{where } n \in N$$

This says that the vector change in the location of a nation n is a function of the previous location of that nation and the control vector. The control vector, $\underline{u}$, is the change in the location of the controlling nation.

N^t; nation label set

You can't tell one nation from another without a score card and this is exactly what this set is.

<u>Capacity of the Formulation</u>

For those of you who are interested in following the mathematics of our simulations rather than hearing the things we say about the simulations allow us to suggest

that you jump directly to the section "A Closer Look at What We Did". Those of you who would rather gossip than slog through matrix manipulation are recommended to read on here.

$$\underline{\dot{x}} = f(\underline{x},\underline{u})$$

Is the standard differental equation notation employed in optimum system control theory. We will interpret this as: $\dot{x}$(the change in location) is a function of x (the old location of the nation, its trajectory, its homing tendency, the changing morality of the citizens etc...) and $\underline{u}$ (the control applied by an outside power). In standard optimum systems control, controls are applied subject to certain constraints. Often the constraints are explicit such as; do not exceed this certain level of control and can be modeled directly into the problem. Other times constraints on the controls enter into the problem only implicitly via a "cost" function which says "achieve this goal, but do it without wasting resources". Both notions of constraint translate nicely into political sciency type concerns. The former might be seen as "we can ask only so much of a sacrifice from our citizenry before they will vote us out of office", while the later can be seen as "if we can achieve our goal by spending n dollars lets be sure we don't spend 2 times n dollars". The notion of the differential equation and the capacity of constrained control seem to be nicely built for doing theorizing of a complex sort wherein

the values of one variable are bound up in the values of the others, only some are controllable and those only to a limited extent.

A Closer Look At What We Said

For those of you who would rather not wade through an exercise in matrix algebra, the main points are summarized in "A Non-Technical Summary..." which follows this section.

At the heart of the state transition function modeled here is the concept of a model. The model is used by a nation to forecast the behavior of another nation as influenced by controls (the behavior of the nation doing the influencing). As a simple example consider the following:

Assume the state space has only one dimension, S. There are two nations, N^1 and N^2. We will take the perspective of N^1 trying to move N^2 to some point on S, call it S_g. (It should be remembered that the presentation in this section is of a single time slice. When we create our system, each nation will respond to the other nation according to the illustration presented here for only one nation.) We will allow our nations to have one of two models. The first model, the conciliatory model, states roughly that the only way N^1 can get N^2 to move to N^1's goal, S_g, is to move closer to N^2's current position on S. Or, $\dot{x} = -u$, where $\dot{x}$ equals the change in position of N^2 and u equals the change in position of N^1. What this says

is that the change in the other nation's behavior, $\dot{x}$, will be in the opposite direction from my behavior, u. Since N^1 wants N^2 at S_g, N^1's behavior is determined as follows: $Gd = S_g - S_n2$; where S_n2 is the position of N^2 on S. GD is the difference between N^1's goal and N^2's position, or it is the goal difference. N^1 would like N^2 to move to S_g. In order for N^2 to get to S_g it would have to move GD units on S. It therefore follows that $\dot{x}$ would be set to GD to solve for N^1's behavior, u.

$$GD = \dot{x}$$
$$GD = -1 \cdot u$$
$$u = -1 \cdot GD.$$

Thus N^1 will move -GD units on S with the expectation that N^2 will move to S_g. Thus if $S_n1 = 5$, $S_n2 = 10$, and $S_g = 8$:

$$GD = 8 - 10$$
$$GD = -2$$
$$u = 2$$

N^1 will move to position 7 ($S_n1 + u$), and then will expect N^2 to move to 8 ($S_n2 + \dot{x}$).

The other model that we will allow our nations to have is the force model. The force model states that the only way I can get the other nation to move to my goal is to show him how strong I am by moving away from him. In our notation, the force model is expressed as follows: $\dot{x} = u$. Substituting this function above, N^1 will move to 3 and expect that N^2 will move to 8.

Both of these examples are illustrated in Figure VI.

Insert Figure VI Here

These single dimension models can easily be translated to n--dimensional state space conditions. The conciliatory model becomes $\underline{\dot{x}} = -I \cdot \underline{u}$, where I equals an n x n identity matrix, and $\underline{\dot{x}}$ and $\underline{u}$ are the same as $\dot{x}$ and u, except they are vectors of length n. The force model is therefore $\underline{\dot{x}} = I \cdot \underline{u}$.

To this very simple model (which assumes that N^2 does not move on its own) we add another element which specifies N^2's behavior if N^1 did nothing: $\underline{\dot{x}} = \pm I \cdot \underline{u} + T \cdot \underline{s}_n2$. In this model, $\underline{\dot{x}}$, I, and $\underline{u}$ are defined as above. $\underline{s}_n2$ is simply the position of N^2 in the state space, and T is defined as a trajectory matrix. The trajectory matrix describes the behavior of a nation as a function of its current position. Thus the current location multiplied by the trajectory matrix gives an estimation or projection of the nation in one time period. This projection is based upon the assumption that N^1 did nothing. Thus if the T matrix projected that N^2 would go the N^1's goals, N^1 would do nothing. Thus in a sense, N^1 checks where N^2 is headed before deciding upon an appropriate action. The behavior of this model can be illustrated by the following numerical example of a conciliatory image of the environment:

$$S_g = \begin{pmatrix} 5 \\ 3 \end{pmatrix} \quad S_{n^1} = \begin{pmatrix} 2 \\ 2 \end{pmatrix} \quad S_{n^2} = \begin{pmatrix} 7 \\ 5 \end{pmatrix}$$

$$I = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} \quad T = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$GD = S_g - S_{n^2} = \begin{pmatrix} 3 \\ -1 \end{pmatrix}$$

As above, N^1 computes $\underline{u}$ such that $S_{n^2} = S_g$.

$$GD = I\underline{u} + TS_{n^2}$$

$$\begin{pmatrix} 3 \\ -1 \end{pmatrix} = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} u^1 \\ u^2 \end{pmatrix} + \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 7 \\ 5 \end{pmatrix}$$

$$I^{-1} \cdot GD = (I^{-1} \cdot I) \cdot \underline{u} + TS_{n^2}$$

$$I^{-1} \cdot GD = \underline{u} + TS_{n^2}$$

$$\underline{u} = T \cdot S_{n^2} - I^{-1} \cdot GD$$

Substituting yields

$$\begin{pmatrix} u^1 \\ u^2 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 7 \\ 5 \end{pmatrix} \quad \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} 3 \\ -1 \end{pmatrix}$$

$$\begin{pmatrix} u^1 \\ u^2 \end{pmatrix} = \begin{pmatrix} 7 \\ 5 \end{pmatrix} - \begin{pmatrix} -3 \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} u^1 \\ u^2 \end{pmatrix} = \begin{pmatrix} 10 \\ 4 \end{pmatrix}$$

If N^1 moves to $\begin{pmatrix} 12 \\ 16 \end{pmatrix}$, $(S_{n^1} + \underline{u})$, N^1 will expect N^2 to move to S_g.

Just as a positive I matrix implies that N^1 moves in the opposite direction as N^2, a positive T matrix implies that without the intervention of N^1, N^2 would move to a state having larger coordinate values.

Up to this point the I and T matrices have been diagonal with either positive or negative unities for elements. By relaxing this restriction, we now move to our final class of models. (Since I no longer is an identity matrix, we save the symbol but change the name: I is called the impact matrix. I specifies the impact that N^1 perceives that its behavior will have on the behavior of N^2.) First let us relax the restriction calling for unities in the major diagonal -- they may now range over the set of real numbers. Without going into a detailed numerical example the following interpretation can be given to the size of the elements of the I matrix: Elements larger than unity indicate that N^1 perceives that its movement along a dimension will cause N^2 to move a greater distance than it moved. Elements less than zero specify that N^1 thinks that it must move a very great distance in order for N^2 to move much at all. Depending upon the size of the elements of the T matrix, N^2 is either accelerating or decelerating in its movements in state space.

The final bit of tinkering we do with our models is to allow off-diagonal elements of the I and T matrices to assume other than zero values. Contaminating the matrices in this way has the implication that in the case of the I matrix,

movements along one dimension by N^1 will influence N^2's behavior or movement on both (in our two dimensional state space) dimensions. An impact matrix of this sort is: $\begin{pmatrix} 1 & .5 \\ .5 & 1 \end{pmatrix}$. A movement of one unit along the first dimension would, from the perspective of N^1, be expected to cause the other nation to move 1 unit on the first dimension and .5 units on the second.

This completes our exposition of the class of models that we will consider. The remainder of this paper will display the results generated by two nations interacting according to the various response models presented here and discuss the results from the perspective of the impact of model form upon the stability of the system.

Non-Technical Summary of A Closer Look...

What we did in "A Closer Look ..." was to lay out the mathematics of the state transition function. Our formulation of the state transition is built upon the notion of a forecasting model discussed above. Our nations can have one of two models -- a conciliatory or a force model. The conciliatory model "says" that if I move toward another nation in state space, the other nation will respond by moving toward me. In other words, you give up something with the expectation of getting something in return. The force model "says" that if I move away from the other nation, the other nation will move toward me. In other words, if I show the other nation my strength by moving away from him, he will follow in my direction.

Each nation has a goal for the other nation in state space. In essence a nation desires to determine a movement that it can take that will result in the other nation moving to the goal the behaving nation has for the target nation.

The models that each nation uses in determining its appropriate behavior is made up of two components: 1) how responsive the other nation is to its behavior and; 2) where the other nation would move to if the behaving nation did nothing. These two components are called impact and trajectory respectively. Large absolute values in the impact component specify that the other nation is very responsive to movements by the behaving nation. A small absolute value indicates that the behaving nation's impact on the behavior of the other nation is small. A model with positive impact coefficients is the force model, while negative coefficients indicate the conciliatory model.

The size and sign of the trajectory coefficients indicate the direction and size of the movement of the other nation if nothing were done.

Once this basic structure is laid out, " A Closer Look..." generalizes the equations into an "n" dimensional state space. Although the model is capable of employing any number of dimensions in the state space, for our purposes we use only two, since that is the most complex formulation that can easily be graphed on paper.

What We Did

In order to determine the characteristics of our state transition functions, we develop three types of international systems, one for each combination of force and conciliatory transition functions, and simulated their behavior:

	Model for Nation 1	Model for Nation 2
S1:	force	force
S2:	conciliatory	conciliatory
S3:	conciliatory	force

We had expected that there would be a distinct type of behavior exhibited by each of the three types of international systems. While that did not turn out to be the case, our initial presentation will be based upon the classification of model types (force or conciliatory) according to the sign of the impact matrix (- = conciliatory and + = force). Once the initial presentation has been made, we will discuss the factors that determine a force or conciliatory model. As will be seen, we do get the types of behavior that we had posited for the three types of international systems but our use of the sign of the impact matrix for the determination of the model type is incorrect. The next section will discuss some of the shortcommings with our work and some areas that we see as important for further development.

Each of the systems (classified according to our initial expectations) will be discussed in turn.

S1: Force -- Force Models

The typical behavior of a force -- force system is given in Table Ia - Id. (The first table gives the impact and trajectory matrices and goal vectors for each nation. The second table gives a plot of the behavior of the two nations in the two dimensional state space. IN all of our examples, the simulations were allowed to generate fifty pairs of behaviors. The state space dimensions are illustrative only, and hence do not have any substantive meaning attached to them. In all runs of the simulation both nations start in the same position in state space, i.e., nation 1 = (3,5) and nation 2 = (-7,2). Nation 1's movements are indicated by a '1' on the plot, nation 2 by a '2', and those points where both nation's coincide an asterisk, '*' is printed. The plots are minimum to maximum plots. This means that the values of the increments along the two axes are set so that all fifty points will fit on the plot. The orgin is respositioned accordingly. The third and fourth tables five the movements of the two nations along each dimension over time. The two dimensions are respectively the X and Y axes in the full state plot. The starting point in these one dimensional plots is at the top of the page, with each line going down representing one time unit.)

In this first type of system both nations employ what we call a 'force' strategy. This strategy is predicated upon the supposition that a target nation will

respond to threatening behavior be moving toward the forceful nation. As can be seen in Table Ia this is represented in matrix form by positive entries along the major diagonal of the impact matrix. It can be seen that models of this form will cause a nation to move away from a target nation in an effort to pull him to a goal state location.

Our guess was that in a two nation world of force nations the state locations would move in opposite directions. This is born out by our simulation results in Tables Ia - Id.

S2: Conciliatory -- Conciliatory Models

A typical example of conciliatory -- conciliatory systems is given in Table IIa - d. Since the conciliatory model states that another nation will respond positively toward you only if you respond positively toward it, we had initially expected that the two nations would proceed immediately toward the goal locations and sit there. It did not turn out that way. Each nation "walked" toward the other nation, and together they moved towards the extremes of the state space. While it turns out to be the case that the initial position of the two nations vis-a-vis each other does influence their initial behavior, once both nations get on the same side of each other's goals, they move to the extremes together. Thus in a system of conciliatory nations, no nation can achieve its goal. This surprising result, as will be discussed in more detail below, is a function of how we have specified the

state transition functions and should not be taken to be making assertions about a real world description of conciliatory (using the common sense notion of conciliatory) behavior.

S3: Force -- Conciliatory Models

A typical example of force -- conciliatory (or mixed models) is given in Table IIIa - d. The mixed model system illustrates a world in which one nation employs a 'force' strategy and the second employs a 'conciliatory' strategy. We would expect a forcing nation to 'pull' a conciliatory nation to the forcing nation's goal. When we examine the simulation results we see that this is roughly what happens. As nation 1 approaches the goals that nation 2 has for it, nation 2's movements become smaller and smaller. The movement of nation 2 is zero when nation 1 is at its goal. As nation 1 moves over nation 2's goal, nation 2 changes the direction of its movement in an attempt to control the concilliator back to the goal state location. The same sorts of behavioral characteristics are exhibited by the conciliatory nation. As nation A crosses the goal of nation B, nation B changes the direction of its behavior. This flip -- flop results in the sinusoidal character of the single dimensional plots and for the spiral appearance of the full plots.

As was noted above, the sign of the impact matrix is not sufficient to determine the form of the behavior of the

nations. It turns out to be the case that a force model can be made to exhibit the behavior of a conciliatory model. The same holds true for the conciliatory model. Without going into the mathematics of our system of difference equations, the size and sign of the trajectory coefficients and the sign of the impact coefficients are jointly sufficient to predict the behavior of our system. The exact relationship is given in Table IV. We do get the classes of behavior exhibited by what we have called force -- force, conciliatory -- conciliatory, and mixed forms of systems -- but for reasons other than those we had anticipated. Tables Va - VIIId give illustrations of this sort.

<u>Where To Now?</u>

Our initial goal has been to investigate the stability properties of our two nations in state space. It soon became clear that 1) behavior stability was not definable; and 2) even if we could define behavior stability in terms of state space our nations could never (except in degenerate and uninteresting solutions) exhibit state location stability given our definition of the state transition function.

In the broader thrust of our research efforts we intend to construct peaceful international systems and then by introducing our three candidates for accidental war mentioned in the Introduction, assess their impact on national behavior. Although this paper represents just a first attempt to deal with some of these problems -- in the larger context of our research thrust we propose

to represent ideological differences by specifying that the state spaces that the nations operate within are not the same for all nations. The causes of war based upon factual errors will be represented by introducing noise into the perceptions of nations. Accidental war based upon incorrect judgement of the responses to a nation's actions will be based upon incongruous models of the other nation's behavior. It is our intention to first build a perfect world having none of the perturbations mentioned above. Then by systematically introducing our candidates for accidental war, we will be in a position to determine not only if these factors do in fact cause our once stable system to break down, but also how much of a perturbation is required to disrupt the system. Since we do not link our state or orientation space to behavior, stability (defined behaviorally) in our system could not be determined -- since state space alone is not sufficient for the determination of behavior. Recalling our capitalist -- communist one dimensional world, while we would expect the behavior of the two nations to be different, there is as of yet no way to determine in what way they are different. That determination must wait until we have specified the second function machine mentioned in the Big Picture (input × state → output).

The second point mentioned above, the inability of our nations to exhibit state space stability, is a result of our development of the form of the trajectory component

of the state transition function. It will be noted in Table III, the plot of the behavior of the system that took on the least extreme state space positions after fifty iterations, that the nations were oscillating around their goals, but that the oscillations were getting larger and larger. This is a result of the fact that one nation does not pose goals for the other nation. The trajectory component specifies that if a nation did nothing, the other nation will change its position by the trajectory times the current location. Thus even if both nations were sitting at the goals that each nation had for the other, both nations (assuming other than zero trajectory coefficients) will move, since neither nation realizes that both nation's goals are completely satisfied at that particular state space location configuration. Thus our immediate task is to determine alternate forms of the trajectory influence. But beyond that before we are in a position to talk about causes of accidental war we must flesh out the skeleton that we have put forth here, and make our concepts of state, state transition, output function, and behavior space explicitly operationalizeable. We have a long way to go -- but we knew it wasn't going to be easy when we started.

Appendix on Dynamic Systems *

i) A (general) time system is a system such that:

$X = A^T$, $Y = B^T \rightarrow S \subsetneq A^T \times B^T$; where A and B are alphabets and T a linearly ordered time set.

ii) A dynamical system is a time system for which there are given a set Z and a pair of functions:

$p: Z \times X \times T \rightarrow Y \times T$

$\phi: Z \times X \times T \times T \rightarrow Z$

such that:

$(\exists Z)\ \{p(Z,X,T) = (Y,T)\} \leftrightarrow (X,Y) \in S$

$p(\phi(X,Y,T,T'),X,T') = (Y,T')$

common reference is:

Z = state space

p = state representation or system response function

ϕ = state transition function

Although to the casual reader the Mesarovic formulation might seem prohibitively rigorous the notion of the dynamic systems is in fact a common sense one and can be found in one form or another in many places. One such popular formulation that is a close cousin to dynamic systems is the Arbib (1964) finite automaton: "def; a finite automaton is a quintuple, $A = \langle I,O,S,\delta,\lambda \rangle$ where: I = finite set of inputs; O = finite set of outputs;

---

* this follows closely the development by Mihalo Mesarovic in George Klir's Trends in General Systems Theory

S = finite set of internal states; λ: S × I → S, (next state function; and δ: S × I → O, (next output function). An examination of the Arbib automata shows it to be a special case of the dynamic system. It is noted that present work by the authors is done in realm of development of a reasonable ϕ function and an exposition as to the utility of developing dynamic systems models of international behavior.

Appendix on Control of Dynamic Systems: An Introduction for Poets

For many years physical phenomena have with notable success been controlled. This means that a physical process was brought to a desired condition. Remembering our systems vocabulary, a preferred appearance of the system was controlled so that it obtained. More strongly than a mere occurance of a desired appearance, physical processes have been controlled while minimizing some objective function. For example rockets might be sent to the moon while minimizing time, or energy, or total cost. A plane might be directed to land subject to a minimum number of direction changes. While success has been rather stunning for circuitry, social planning has managed to avoid direct application of optimal control techniques. It is the guess that social processes are in principle modelable that leads us to do science at all and the further suspicion that if a process is modelable we might as will cast it up in language that is amenable to control. Seen in perspective this is but the ground breaking for an enormous enterprise, the empirically useful formulation of inter-nation behavior in formal control theoretic language and the application of control theory to those formulations.

Formalizing Controllability:

Controllability is defined in reference to the objective of control. Let $S: M \times U \to Y$ be the system and $G: M \times Y \to V$ the performance function. Also, M is the control object,

while U can be the set of initial states or disturbances. S is controllable in $V' \subseteq V$ over $U' \subseteq U \leftrightarrow (v)(v \in V')$, $(u)(u \in U')$, $\exists\, m \rightarrow \{v \in V' \text{ and } u \in U' \rightarrow G(m, Sm, w) = v)\}$.

Appendix on Matrix Arithmetic

Addition:

i) is defined only if the matrices to be added are of the same dimension and addition of the elements is defined.

A is $m \times n$ and B is $p \times q$; we can add A+B iff $m = p$, $n = q$, and a_{ij}, b_{ij} are elements of the same field (see appendix on fields).

ii) where addition is defined $A+B = C$ implies $c_{ij} = a_{ij} + b_{ij}$.

Example:

$$A = \begin{pmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{pmatrix} \quad B = \begin{pmatrix} 7 & 8 & 9 \\ 10 & 11 & 12 \end{pmatrix}$$

$$A+B = \begin{pmatrix} 1+7 & 2+8 & 5+9 \\ 4+10 & 5+11 & 6+12 \end{pmatrix}$$

Multiplication by a Scalar

A is an element of field F where A has m rows and n columns. α is some element of field F:

$$\alpha \cdot (A) = \begin{pmatrix} \alpha \cdot a_{11} & \alpha \cdot a_{12} & \cdots & \alpha \cdot a_{1n} \\ \vdots & \vdots & \cdots & \vdots \\ \alpha \cdot a_{m1} & \alpha \cdot a_{m2} & \cdots & \alpha \cdot a_{mn} \end{pmatrix}$$

and $\alpha \cdot (A) = (A) \cdot \alpha$.

Multiplication of Two Matrices

$C = A \cdot B$: A is an element of $F_{m,n}$; B is an element of $F_{p,q}$. Multiplication is defined only if $n = p$

and the entries are from the same field. C will be an m by q matrix with

$$c_{ij} = \sum_{k=1}^{n} a_{ik} \cdot b_{kj}$$

Example:

$$A = \begin{pmatrix} 1 & 2 \\ 3 & 4 \end{pmatrix} \quad B = \begin{pmatrix} 5 & 6 \\ 7 & 8 \end{pmatrix}$$

$$C = A \cdot B = \begin{pmatrix} 5+14 & 6+16 \\ 15+28 & 18+32 \end{pmatrix}$$

Special Matrices and Operations

Transpose:

A' is defined as transpose of matrix A, let $B = A'$, then $b_{ij} = a_{ji}$ for all i,j.

Identity Matrix:

I is a square matrix (n by n) with 1's in the major diagonal and 0's every where else. $A \cdot I = I \cdot A$.

Inverse Matrix:

A is an n by n element of $F_{n,n}$; if there exists a matrix A^{-1} such that $A \cdot A^{-1} = I_{n,n} = A^{-1} \cdot A$, then A^{-1} is the inverse of matrix A.

Appendix on Fields

Let F be a set of elements: $F = \{\alpha, \beta, \gamma, \delta \dots\}$.

F is a field if and only if:

i) addition

Given α, β, any pair of elements from F, their sum $(\alpha + \beta)$ is an element of F which is uniquely defined and:

a1) $\alpha + \beta = \beta + \alpha$, $(\alpha,\beta)(\alpha,\beta \in F)$

a2) $\alpha + (\beta + \gamma) = (\alpha + \beta) + \gamma$, $(\alpha,\beta,\gamma)(\alpha,\beta,\gamma \in F)$

a3) there is an element in F, denoted by 0, such that $\alpha + 0 = \alpha$, $(\alpha)(\alpha \in F)$

a4) for each $\alpha \in F$, there exists an element in F, denoted by $-\alpha$, such that $\alpha + (-\alpha) = 0$ $(\alpha)(\alpha \in F)$

ii) multiplication

Given α, β (any pair of elements in F) their product is a unique element in F and:

m1) $\alpha \cdot \beta = \beta \cdot \alpha$, $(\alpha,\beta)(\alpha,\beta \in F)$

m2) $\alpha \cdot (\beta \cdot \gamma) = (\alpha \cdot \beta) \cdot \gamma$, $(\alpha,\beta,\gamma)(\alpha,\beta,\gamma \in F)$

m3) there exists an element in F denoted by 1 such that $\alpha \cdot 1 = \alpha$, $(\alpha)(\alpha \in F)$

m4) $(\alpha)(\alpha \neq 0)$, there exists an element denoted by α^{-1} such that $\alpha \cdot \alpha^{-1} = \alpha^{-1} \cdot \alpha = 1$

Addition and multiplication are related by:

$\alpha \cdot (\beta + \gamma) = \alpha \cdot \beta + \alpha \cdot \gamma,\ (\alpha,\beta,\gamma)(\alpha,\beta,\gamma \in F)$

Appendix on Vector Spaces

A set together with 1) addition of vectors and 2) scalar multiplication.

$$X = \{\underline{x}_1, \underline{x}_2, \underline{x}_3, \ldots\}$$

the members $(\underline{x}_1, \underline{x}_2, \underline{x}_3)$ are called vectors. X is a vector space if and only if:

a) addition

$(\underline{x},\underline{y})(\underline{x},\underline{y} \in X)$ there exists a unique vector $\underline{x} + \underline{y} \in X$

b) scalar multiplication

$(\alpha)(\alpha \in F)$, where α is a scalar and $(\underline{x})(\underline{x} \in X)$ there exists a unique vector $\alpha \cdot \underline{x} \in X$

Addition and scalar multiplication must satisfy:

i) $\underline{x} + \underline{y} = \underline{y} + \underline{x}$, $(\underline{x},\underline{y})(\underline{x},\underline{y} \in X)$

ii) $(\underline{x} + \underline{y}) + \underline{z} = \underline{x} + (\underline{y} + \underline{z})$, $(\underline{x},\underline{y},\underline{z})(\underline{x},\underline{y},\underline{z} \in X)$

iii) there exists a null vector $\underline{\theta}$ $(\underline{\theta} \in X)$ such that $\underline{x} + \underline{\theta} = \underline{x}$, $(\underline{x})(\underline{x} \in X)$

iv) $(\underline{x})(\underline{x} \in X)$, there exists a unique vector $-\underline{x}$ such that $\underline{x} + (-\underline{x}) = \underline{\theta}$

v) $\alpha \cdot (\underline{x} + \underline{y}) = \alpha \cdot \underline{x} + \alpha \cdot \underline{y}$, $(\underline{x},\underline{y})(\underline{x},\underline{y} \in X)$, and $(\alpha)(\alpha \in F)$

vi) $(\alpha + \beta) \cdot \underline{x} = \alpha \cdot \underline{x} + \beta \cdot \underline{x}$, $(\alpha,\beta)(\alpha,\beta \in F)$ and $(\underline{x})(\underline{x} \in X)$

vii) $(\alpha \cdot \beta) \cdot \underline{x} = \alpha \cdot (\beta \cdot \underline{x})$, $(\alpha,\beta)(\alpha,\beta \in F)$ and $(\underline{x})(\underline{x} \in X)$

viii) $\underline{\theta} \cdot \underline{x} = \underline{\theta}$; $1 \cdot \underline{x} = \underline{x}$

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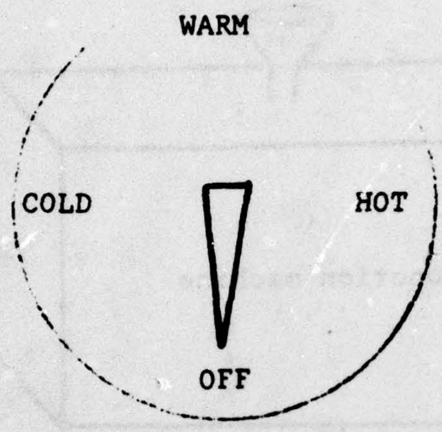
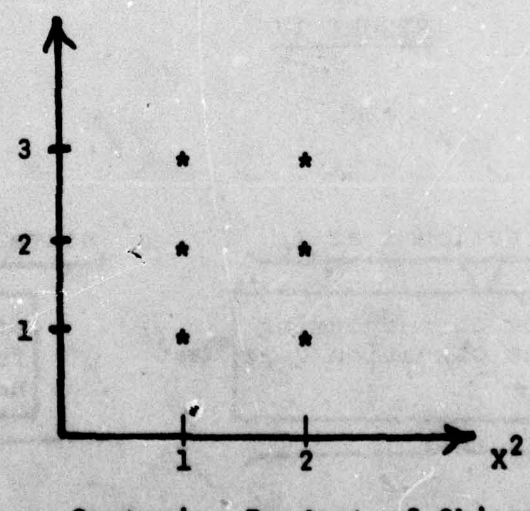
FIGURE I



Mock up of Shower-Control Handle

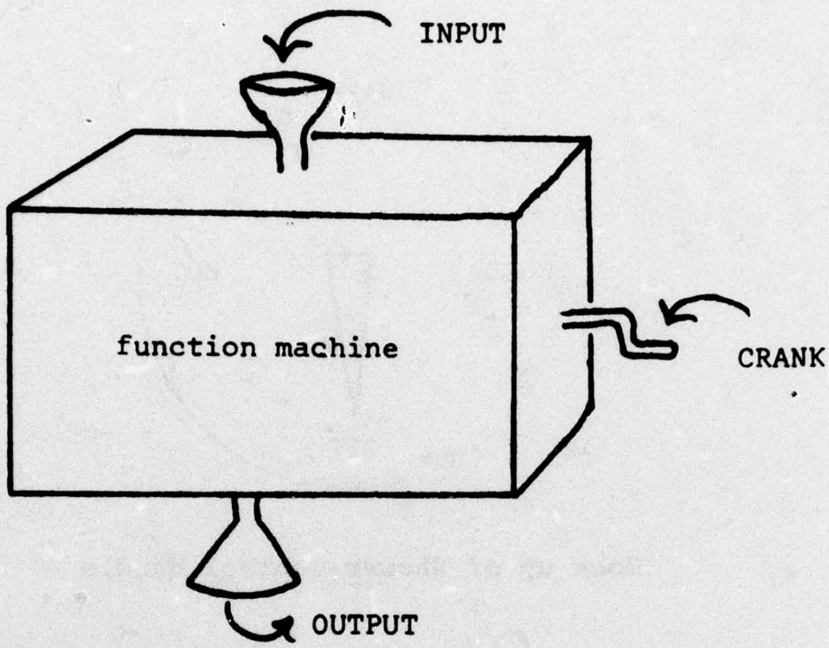
FIGURE II



Cartesian Product of Objects

X^1 and X^2

FIGURE III



FUNCTION MACHINE

FIGURE IV

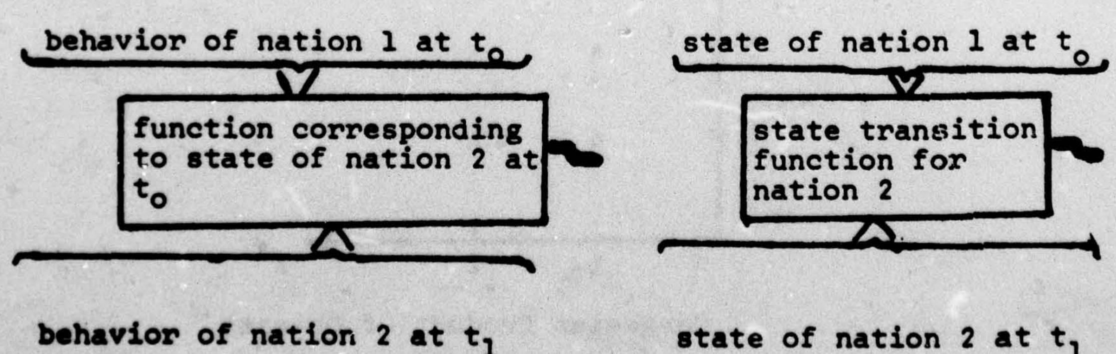
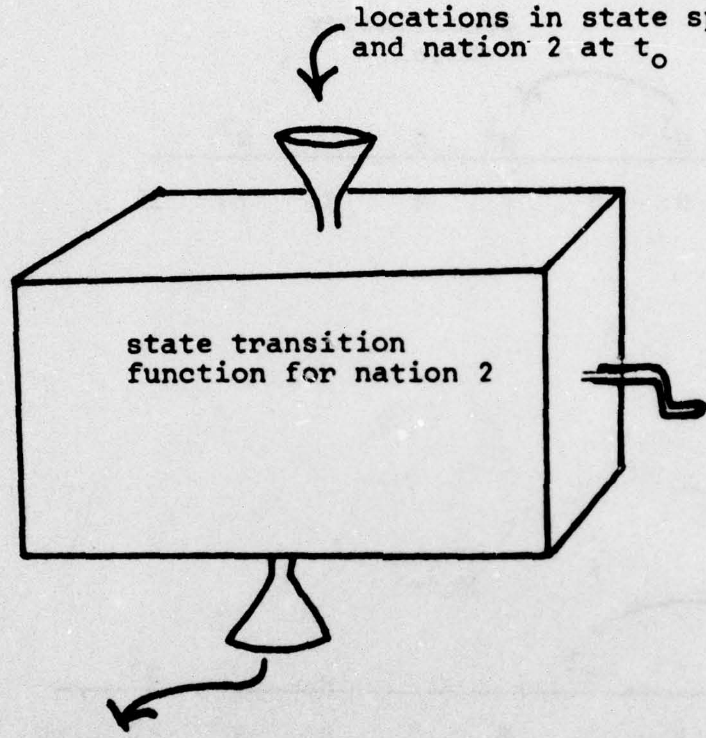


FIGURE V

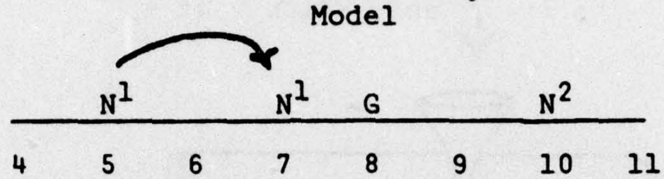
locations in state space of nation 1
and nation 2 at t_o



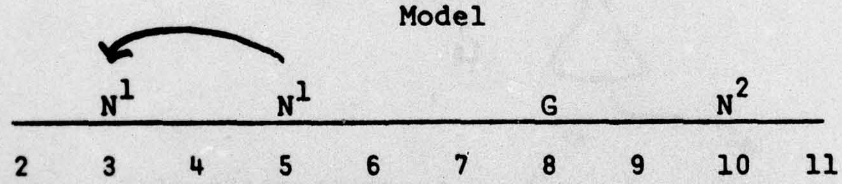
location of nation 2 in state space at t_1

FIGURE VI

Conciliatory
Model



Force
Model



```
NATION 1'S IMPACT =
  2.0000              .0
  .0                  2.0000

NATION 2'S IMPACT =
  4.0000              .0
  .0                  4.0000

NATION 1'S TRAJ =
 -.50000              .0
  .0                 -.50000

NATION 2'S TRAJ =
 -.50000              .0
  .0                 -.50000

NATION 1'S GOAL =        .0               .0
NATION 2'S GOAL =        10.000           15.000
```

FORCE -- FORCE MODELS

TABLE Ia

XMIN = -10314.　　XMAX = 7307.2
YMIN = -40471.　　YMAX = 28639.
X SCALE = 228.85　　Y SCALE = 1410.4

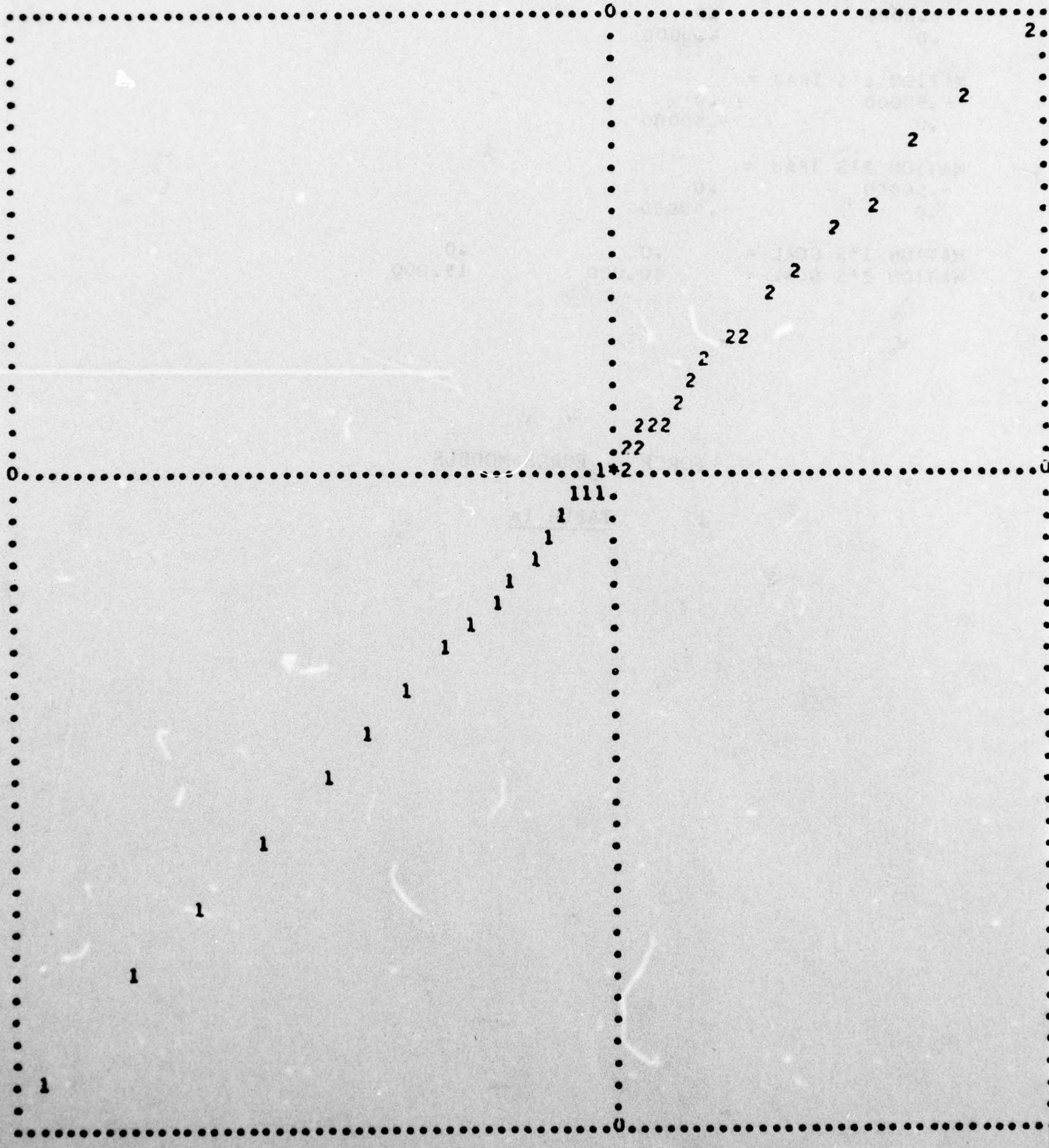


TABLE Ib

FIRST DIMENSION

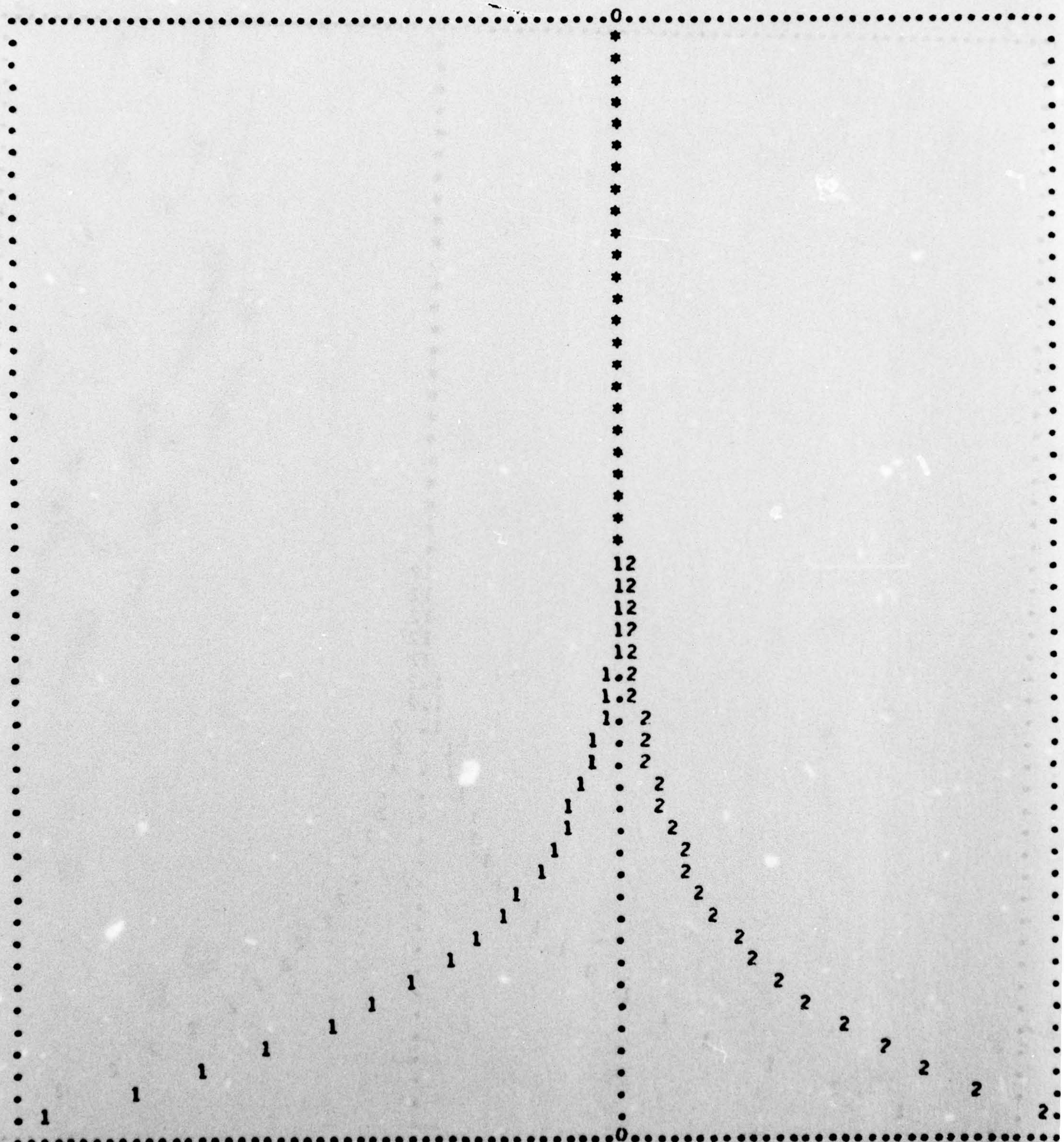


TABLE Ic

SECOND DIMENSION

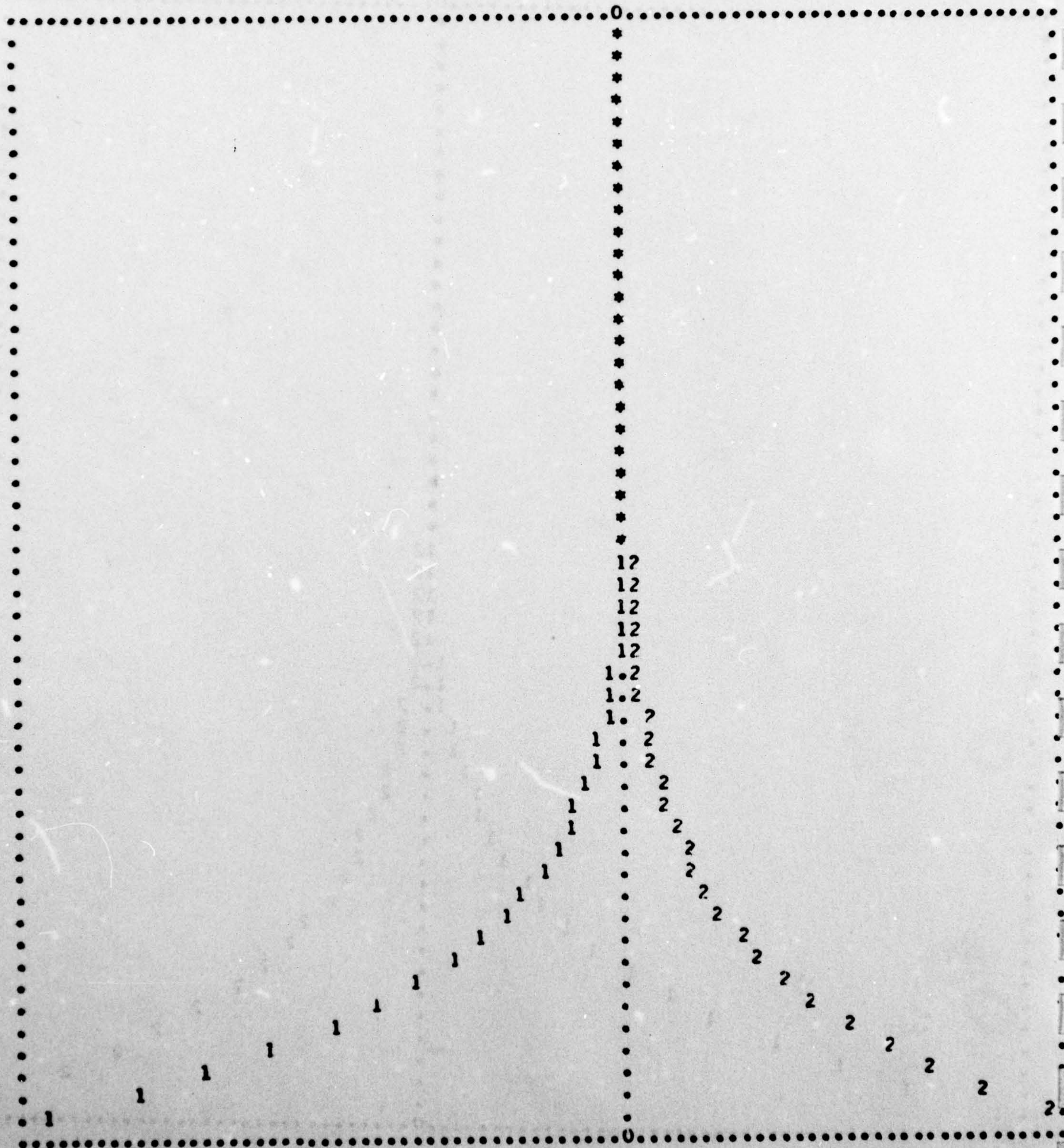


TABLE Id

```
NATION 1'S IMPACT =
 -2.0000              .0
  .0                -2.0000

NATION 2'S IMPACT =
 -4.0000              .0
  .0                -4.0000

NATION 1'S TRAJ =
 -.50000              .0
  .0                -.50000

NATION 2'S TRAJ =
  4.0000              .0
  .0                 4.0000

NATION 1'S GOAL =        .0              .0
NATION 2'S GOAL =        10.000          15.000
```

CONCILIATORY -- CONCILIATORY MODLES

<u>TABLE IIa</u>

XMIN = -.67085E+10 XMAX = 3.0000
YMIN = 2.0000 YMAX = .91140E+10
X SCALE = .87123E+08 Y SCALE = .18600E+09

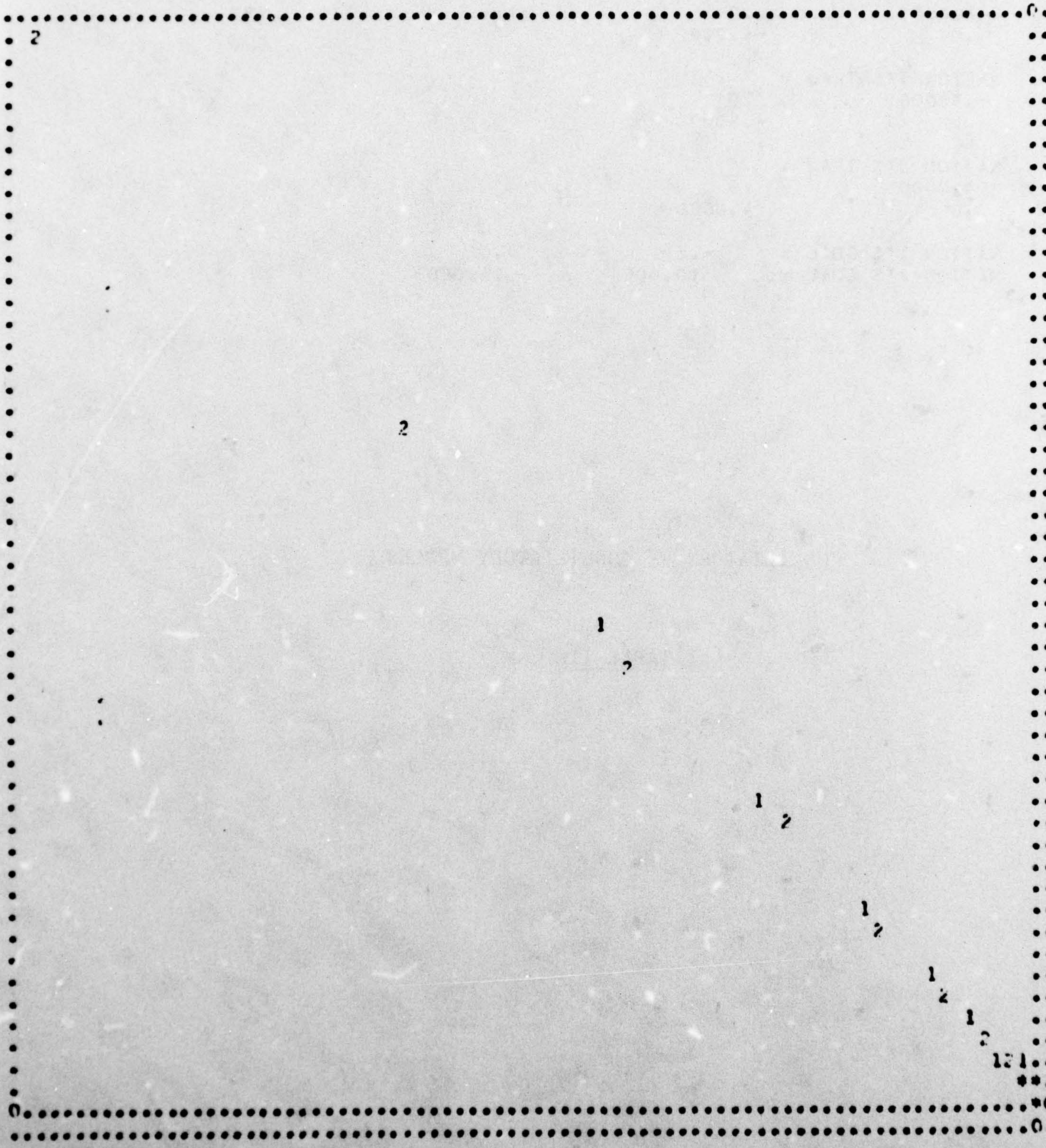


TABLE IIb

FIRST DIMENSION

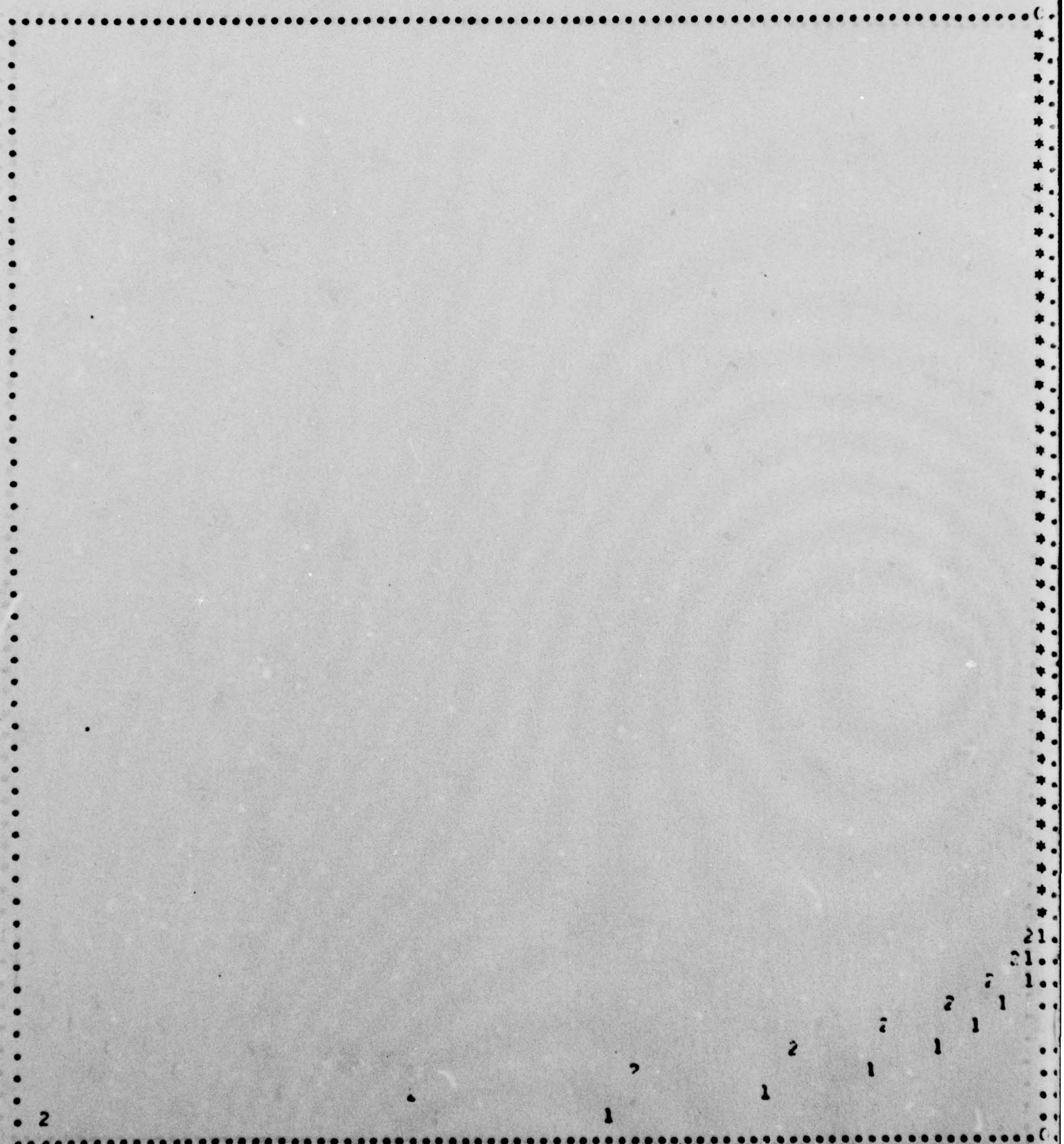


TABLE IIc

FIRST DIMENSION

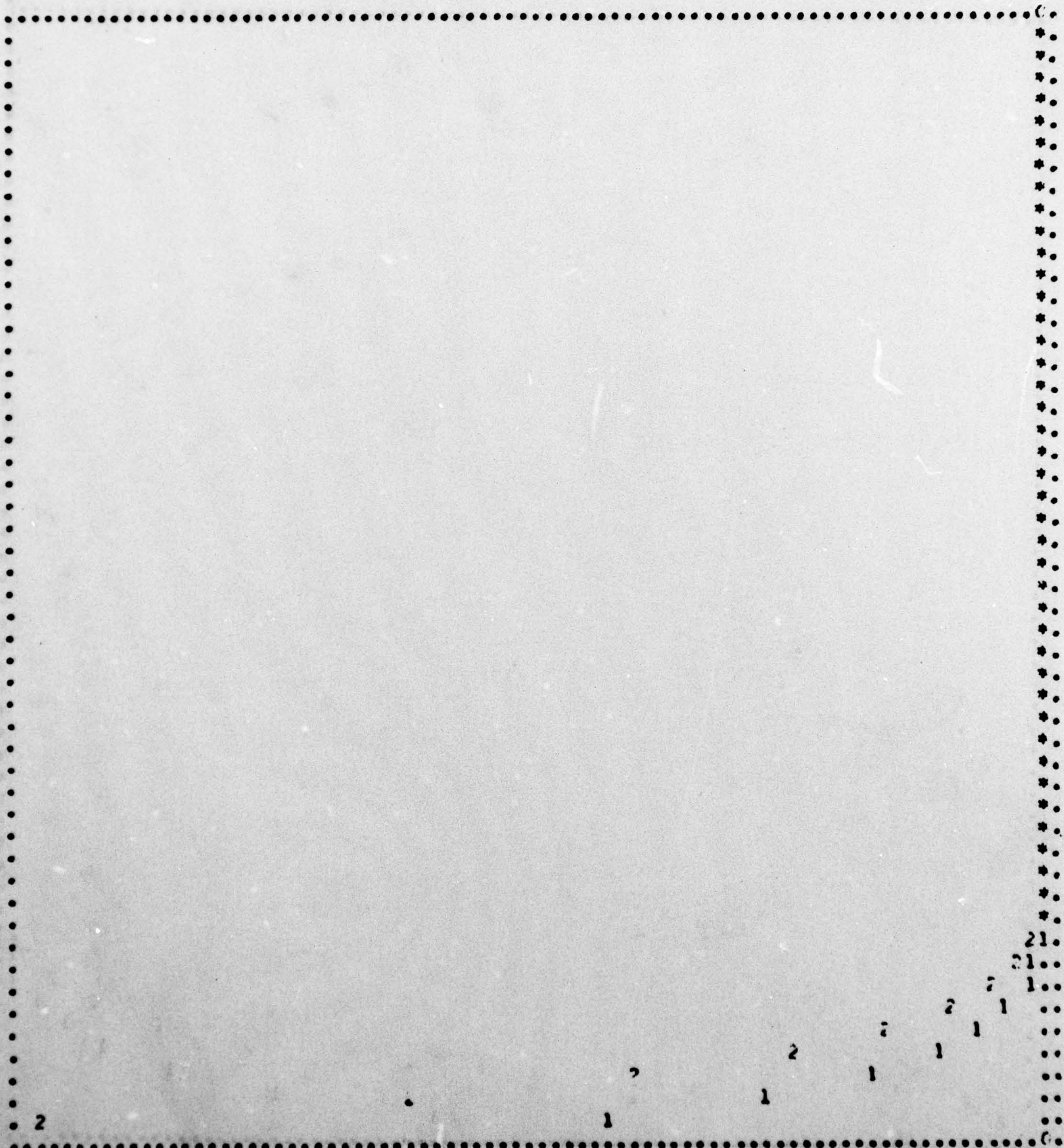


TABLE IIc

"
"

```
NATION 1'S IMPACT =
 -4.0000            .0
  .0              -4.0000

NATION 2'S IMPACT =
  16.000            .0
  .0               16.000

NATION 1'S TRAJ =
 -4.0000            .0
  .0              -4.0000

NATION 2'S TRAJ =
 -2.0000            .0
  .0              -2.0000

NATION 1'S GOAL =        .0              .0
NATION 2'S GOAL =       10.000          15.000
```

MIXED MODELS

<u>TABLE IIIa</u>

SECOND DIMENSION

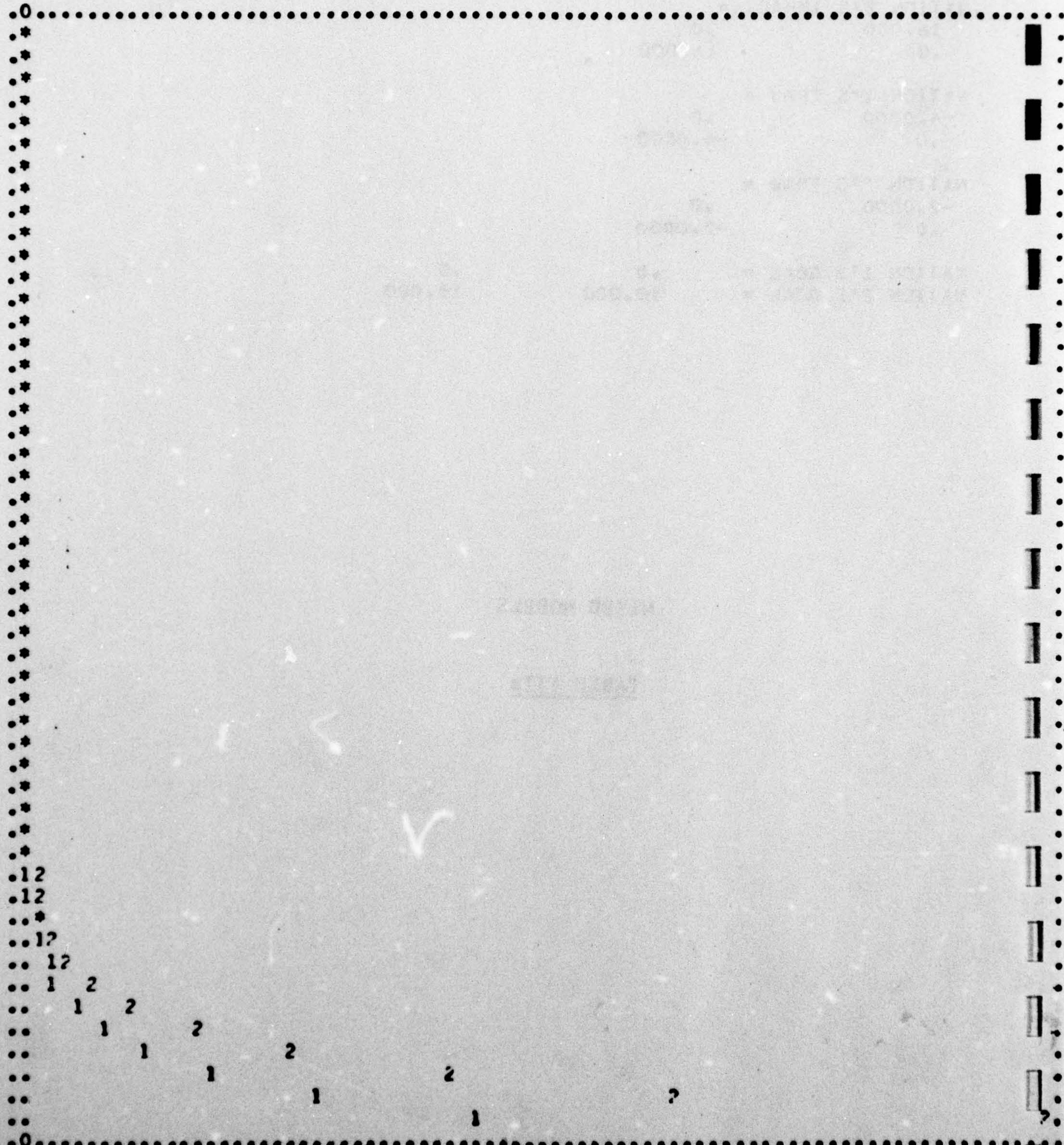


TABLE IId

XMIN = -94.390 XMAX = 51.024
YMIN = -71.505 YMAX = 25.186
X SCALE = 1.8885 Y SCALE = 1.9733

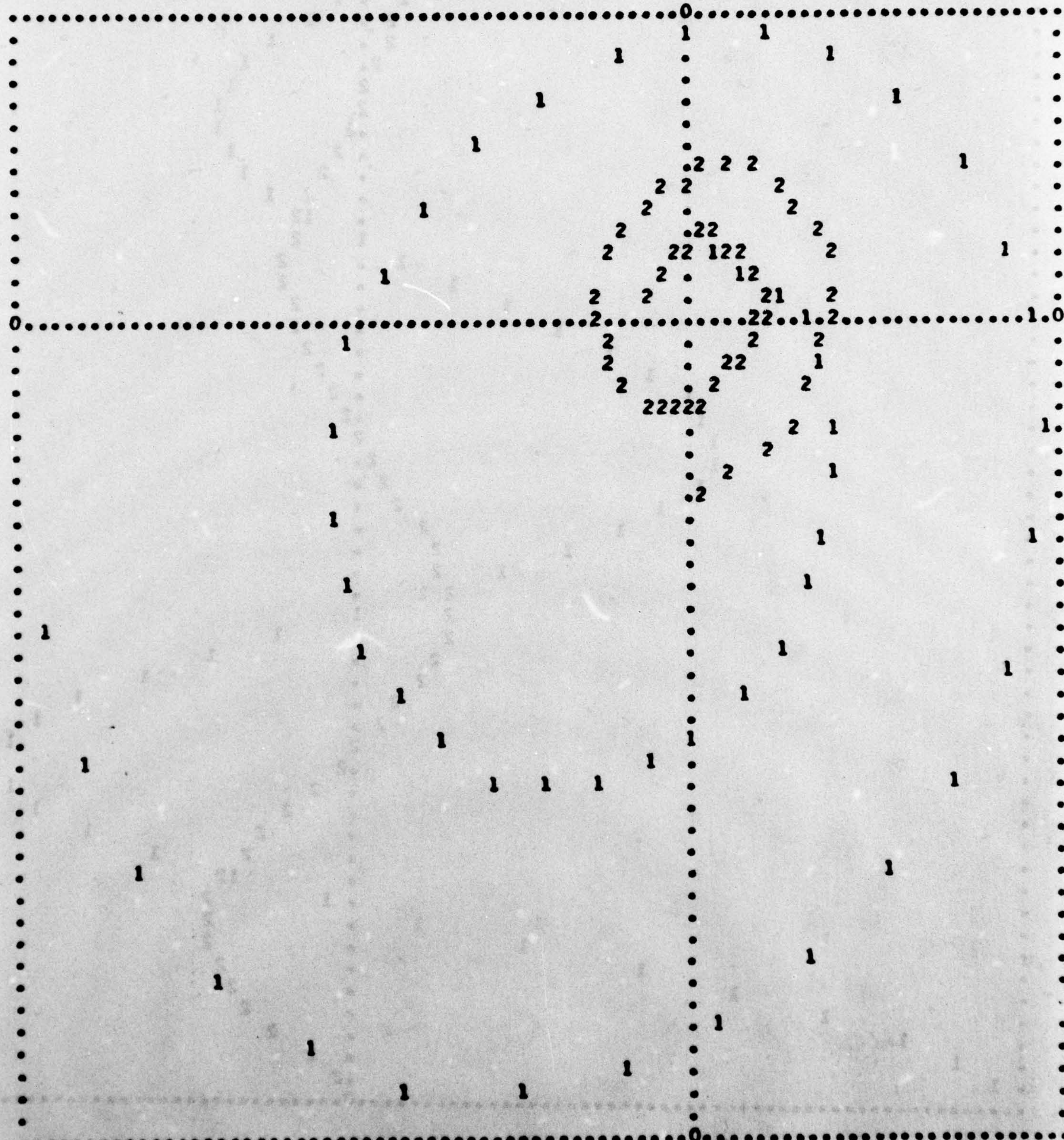


TABLE IIIb

FIRST DIMENSION

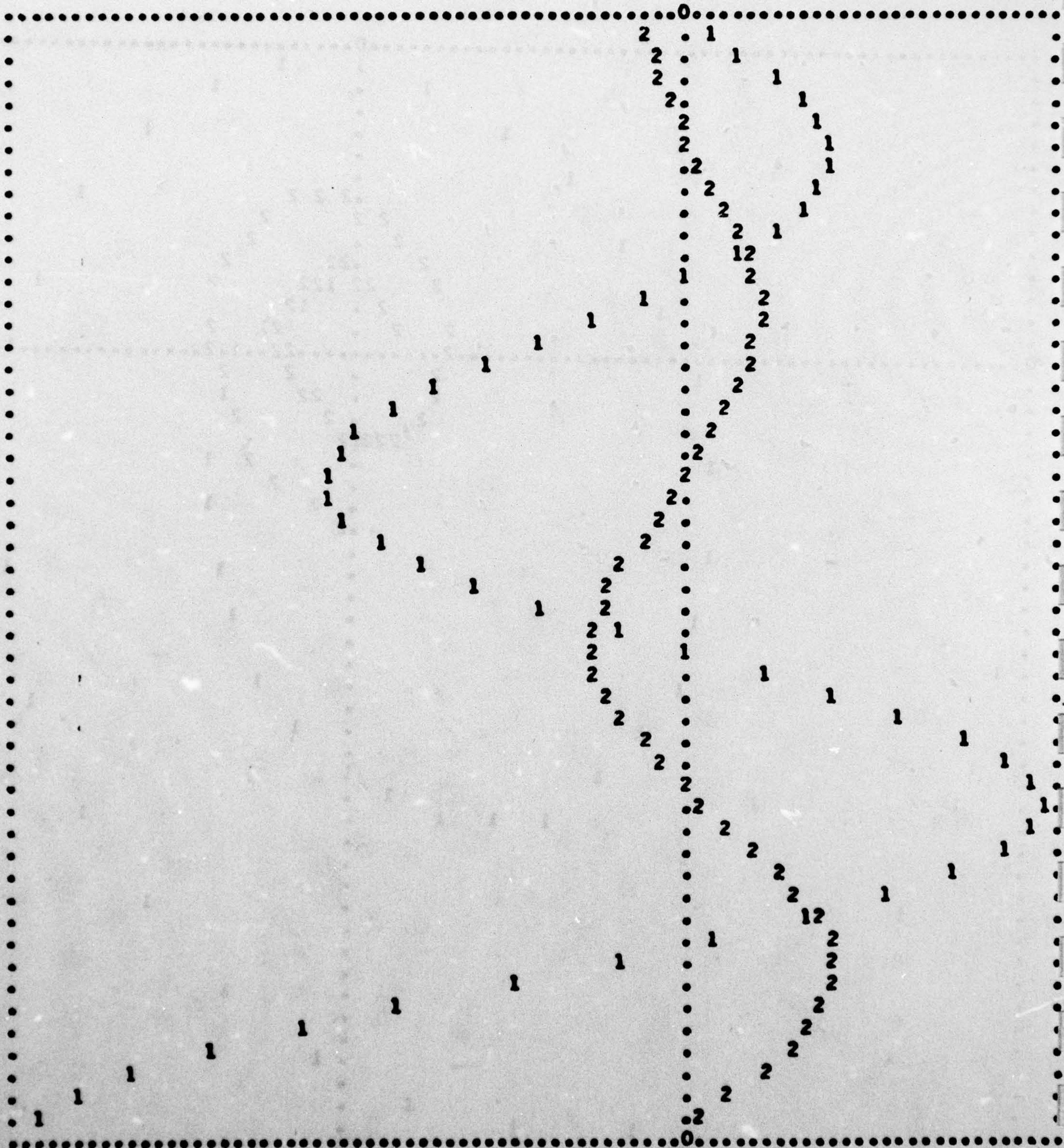


TABLE IIIc

SECOND DIMENSION

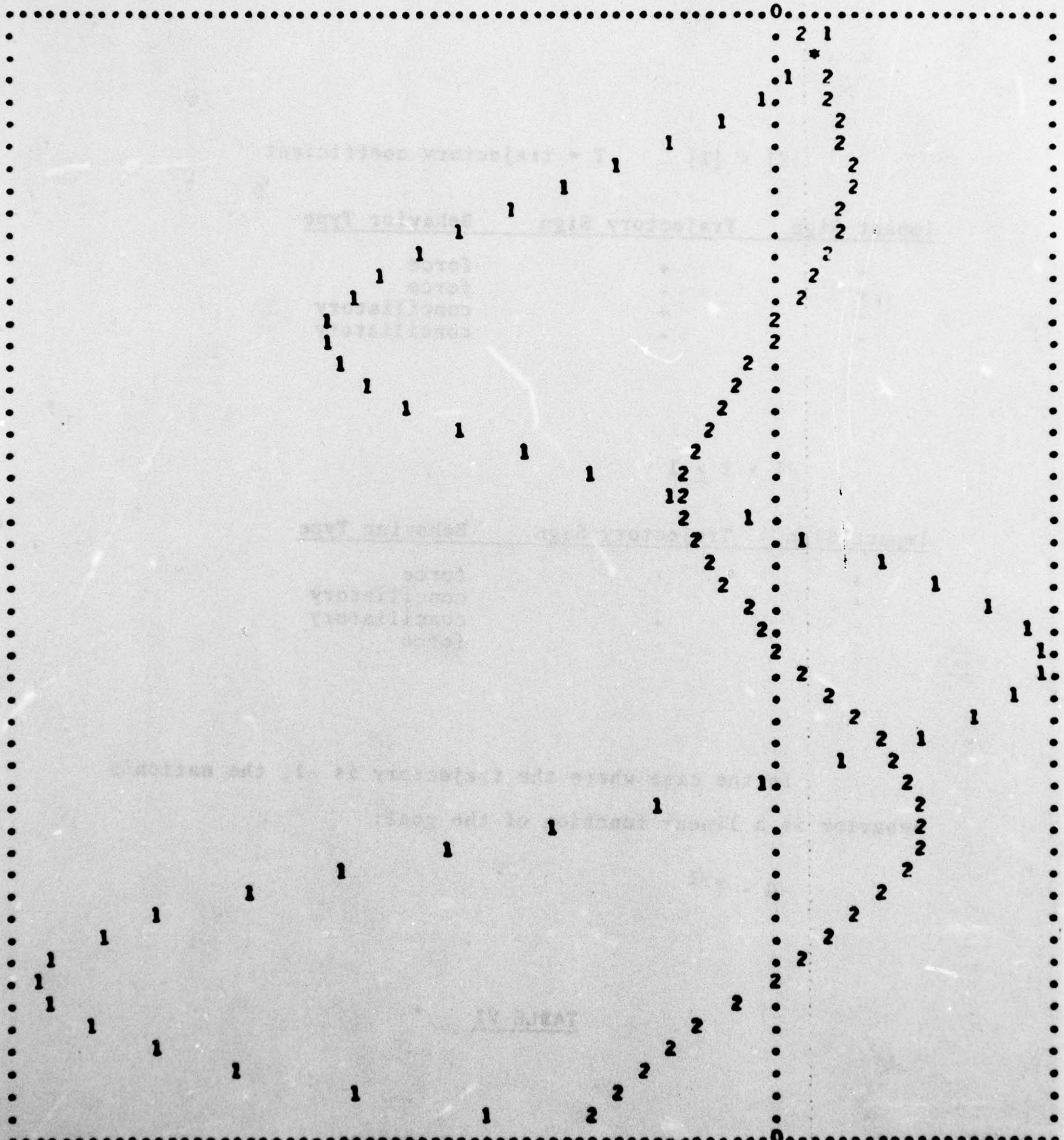


TABLE IIId

$|T| < |1|$ T = trajectory coefficient

Impact Sign	Trajectory Sign	Behavior Type
+	+	force
+	-	force
-	+	conciliatory
-	-	conciliatory

$-1 > T \geq 1$

Impact Sign	Trajectory Sign	Behavior Type
+	+	force
+	-	conciliatory
-	+	conciliatory
-	-	force

In the case where the trajectory is -1, the nation's behavior is a linear function of the goal:

$$-G \cdot I^{-1}$$

TABLE VI

NATION 1'S IMPACT =

2.0000	.0
.0	2.0000

NATION 2'S IMPACT =

4.0000	.0
.0	4.0000

NATION 1'S TRAJ =

-.50000	.0
.0	-.50000

NATION 2'S TRAJ =

-2.0000	.0
.0	-2.0000

NATION 1'S GOAL =	.0	.0
NATION 2'S GOAL =	10.000	15.000

FORCE BEHAVING AS MIXED

TABLE Va

NATION 1'S IMPACT =

2.0000	.0
.0	2.0000

NATION 2'S IMPACT =

4.0000	.0
.0	4.0000

NATION 1'S TRAJ =

-.50000	.0
.0	-.50000

NATION 2'S TRAJ =

-2.0000	.0
.0	-2.0000

NATION 1'S GOAL =	.0	.0
NATION 2'S GOAL =	10.000	15.000

FORCE BEHAVING AS MIXED

TABLE Va

XMIN = -61.351 XMAX = 41.568
YMIN = -78.842 YMAX = 64.430
X SCALE = 1.3366 Y SCALE = 2.9239

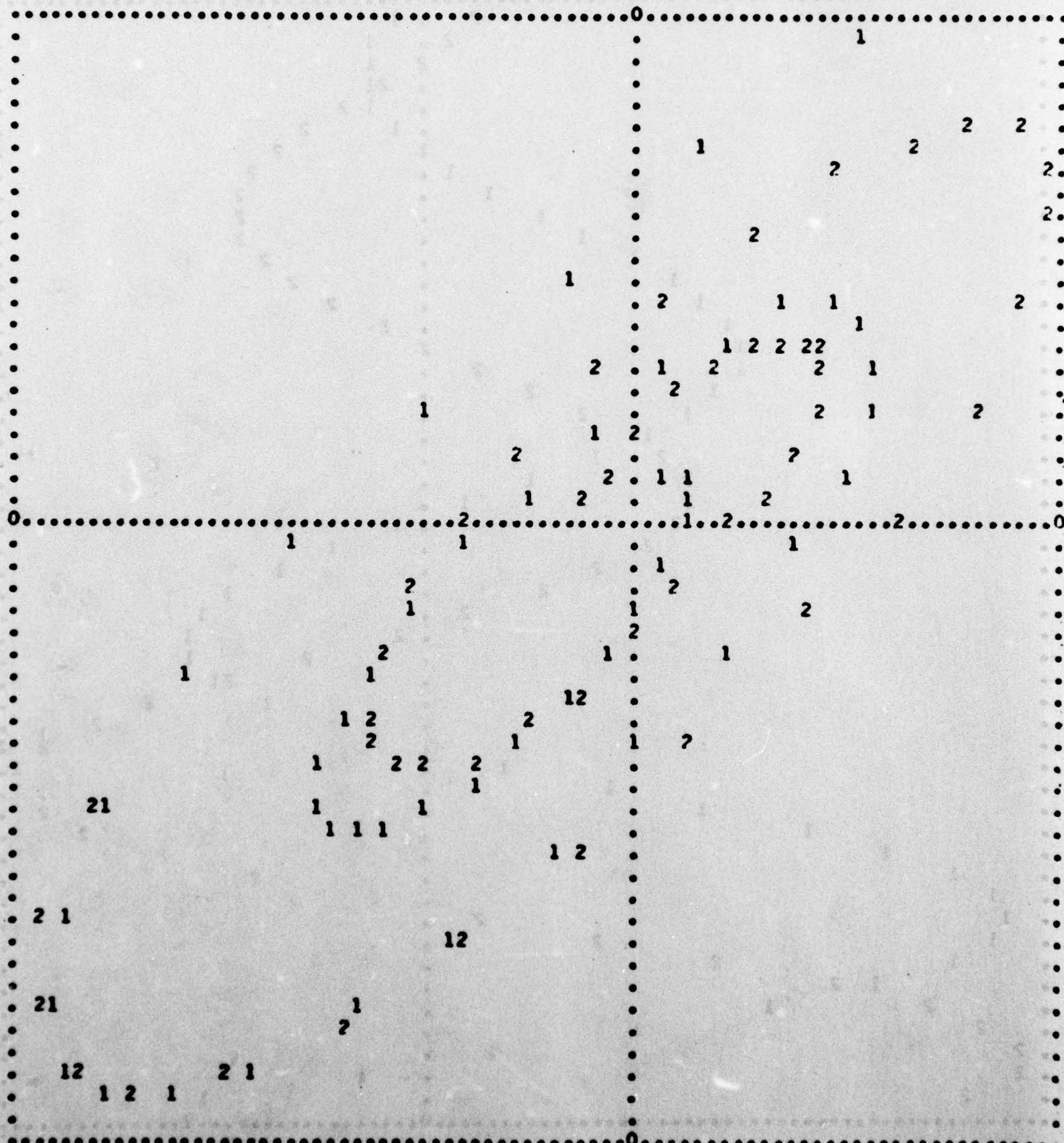


TABLE Vb

FIRST DIMENSION

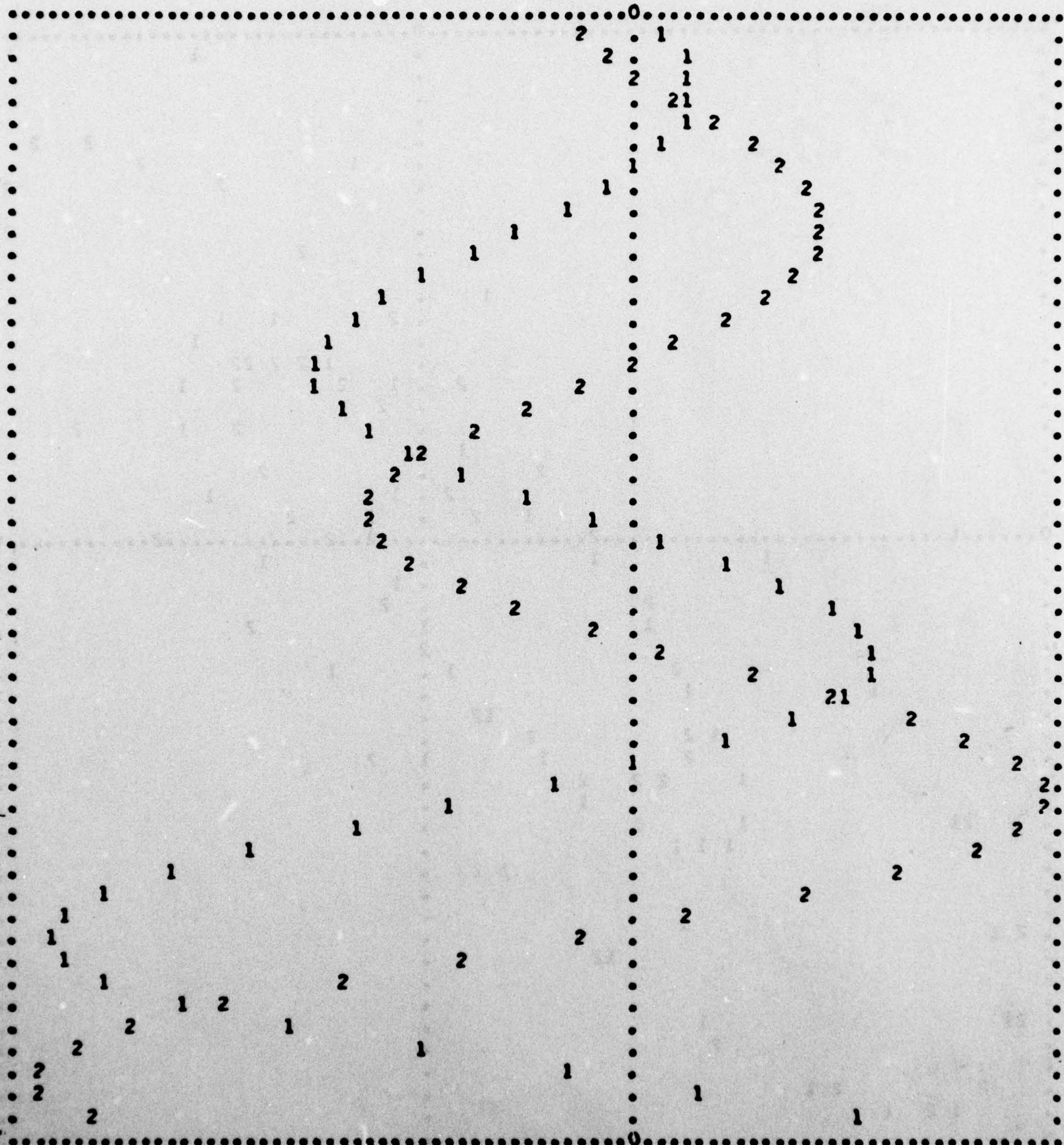


TABLE Vc

SECOND DIMENSION

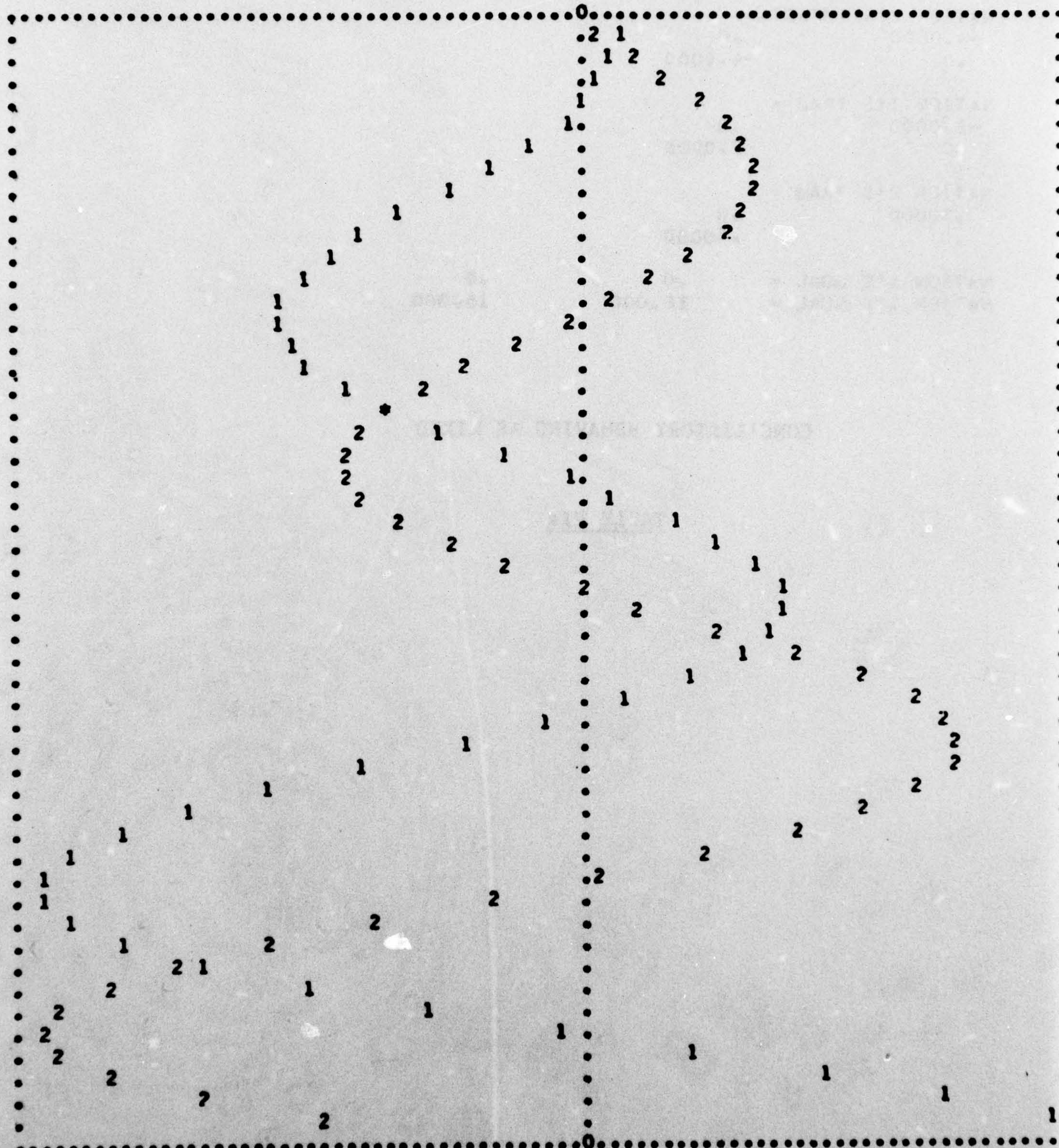


TABLE Vd

```
NATION 1'S IMPACT =
 -2.0000             .0
   .0             -2.0000

NATION 2'S IMPACT =
 -4.0000             .0
   .0             -4.0000

NATION 1'S TRAJ =
 -2.0000             .0
   .0             -2.0000

NATION 2'S TRAJ =
  .50000             .0
   .0              .50000

NATION 1'S GOAL =        .0            .0
NATION 2'S GOAL =        10.000        15.000
```

CONCILIATORY BEHAVING AS MIXED

TABLE VIa

XMIN = -448.19 XMAX = 413.35
YMIN = -311.90 YMAX = 201.64
X SCALE = 11.189 Y SCALE = 10.480

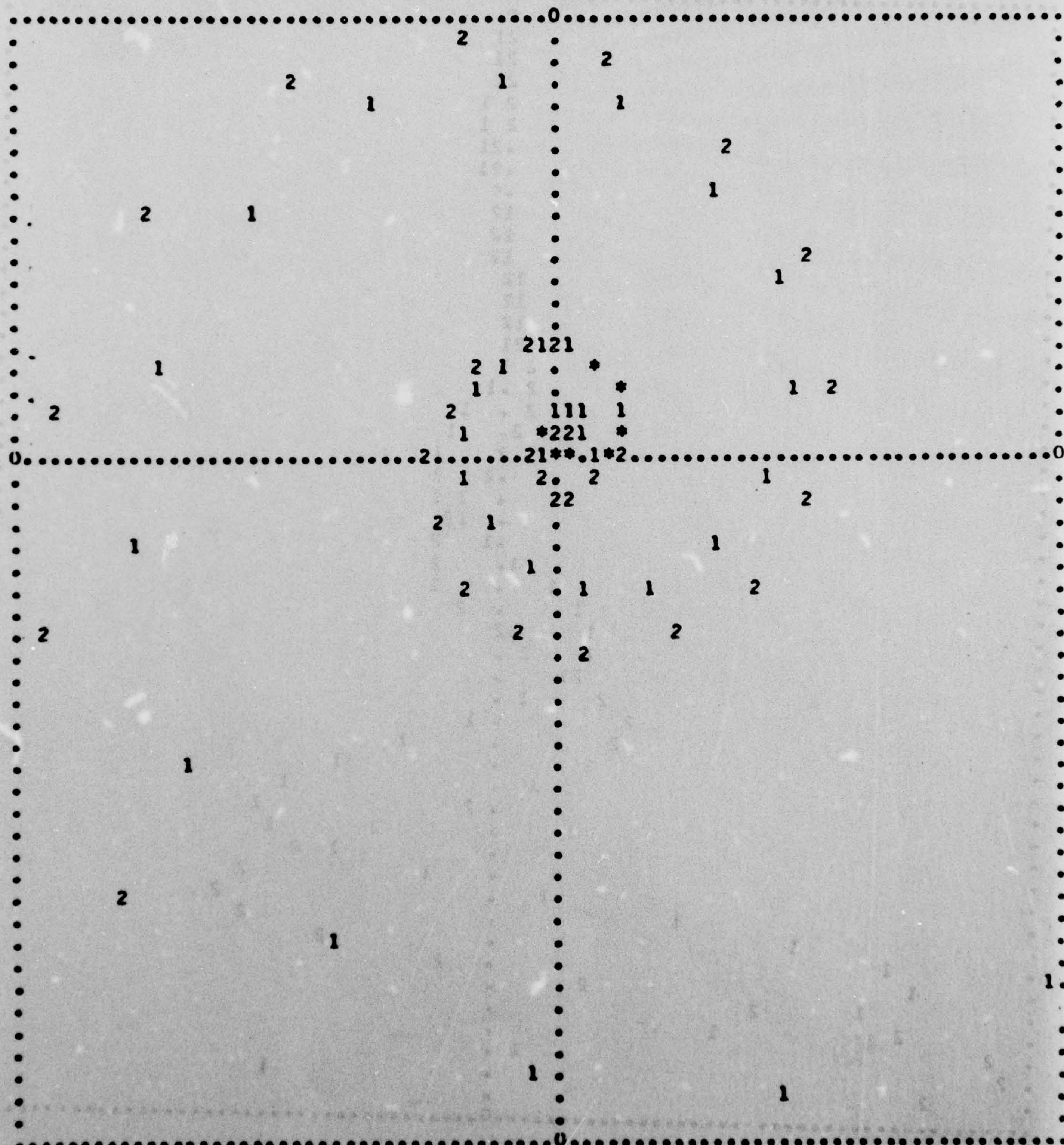


TABLE VIb

FIRST DIMENSION

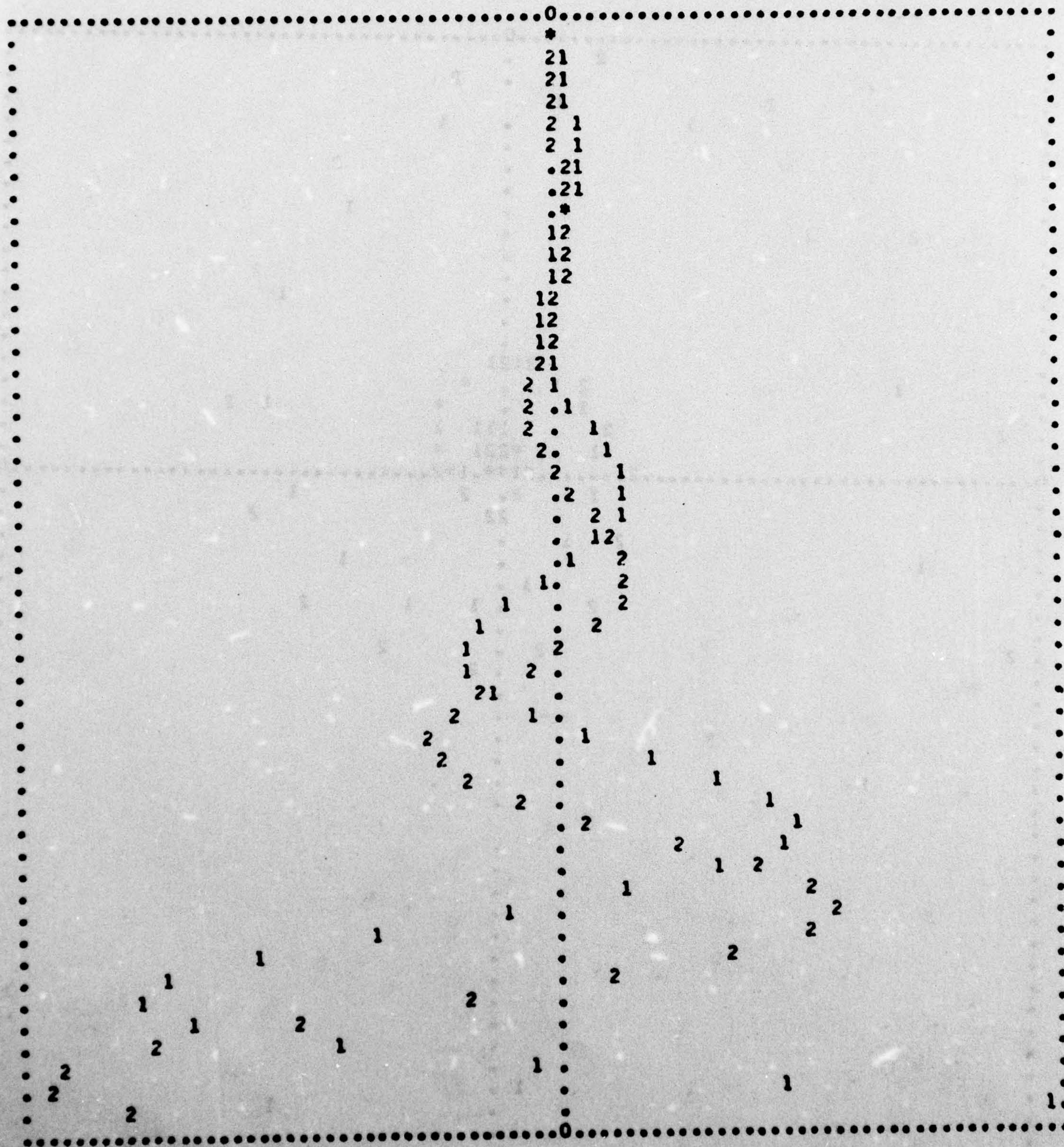


TABLE VIc

SECOND DIMENSION

TABLE VId

```
NATION 1'S IMPACT =
  -4.0000              .0
    .0              -4.0000

NATION 2'S IMPACT =
   16.000              .0
    .0               16.000

NATION 1'S TRAJ =
  -4.0000              .0
    .0              -4.0000

NATION 2'S TRAJ =
   .50000              .0
    .0               .50000

NATION 1'S GOAL =        .0              .0
NATION 2'S GOAL =      10.000          15.000
```

MIXED BEHAVING AS FORCE

TABLE VIIa

XMIN = -.28862E+06 XMAX = .81636E+06
YMIN = -.53926E+06 YMAX = .19066E+06
X SCALE = 14350. Y SCALE = 14896.

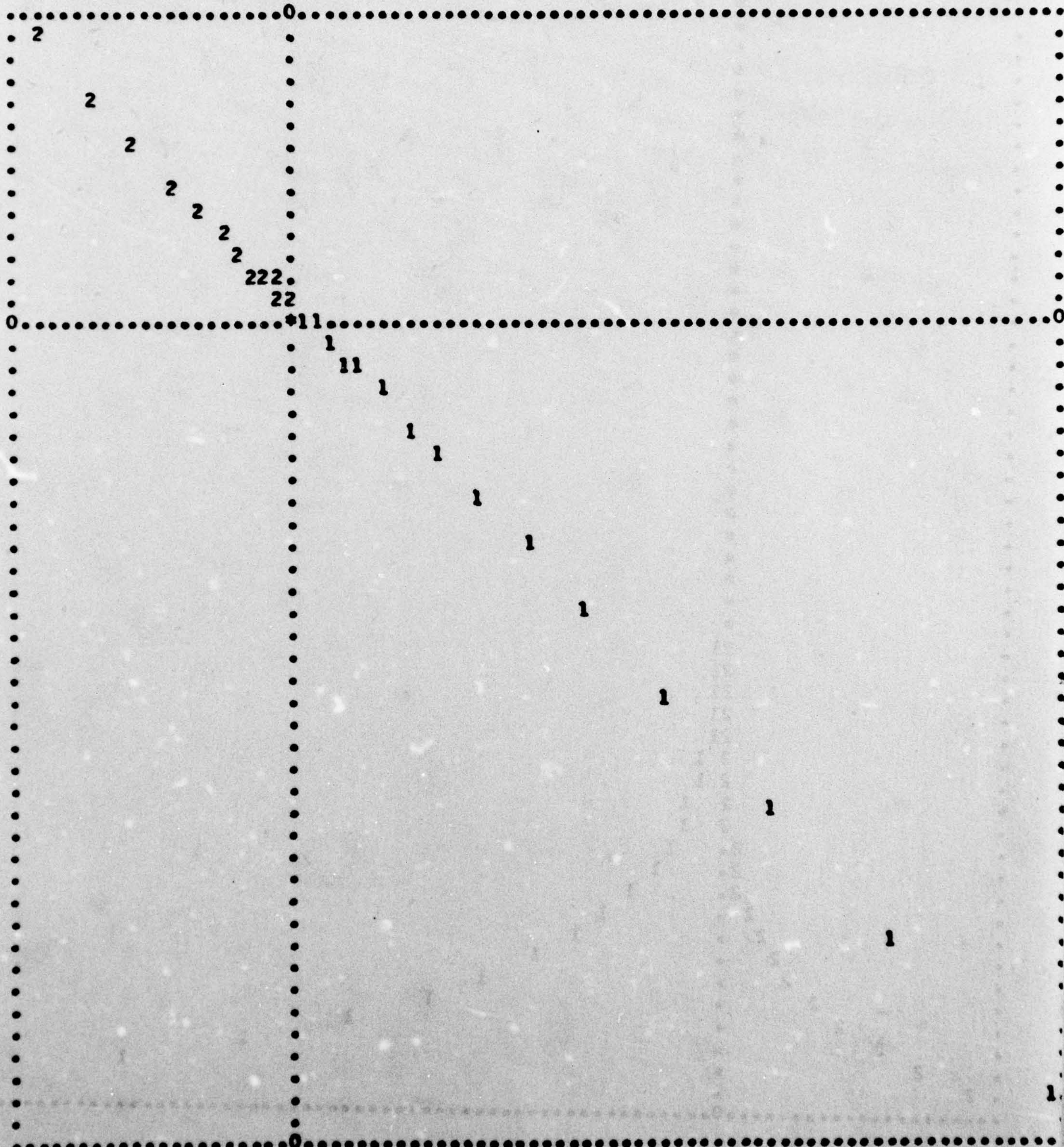


TABLE VIIb

FIRST DIMENSION

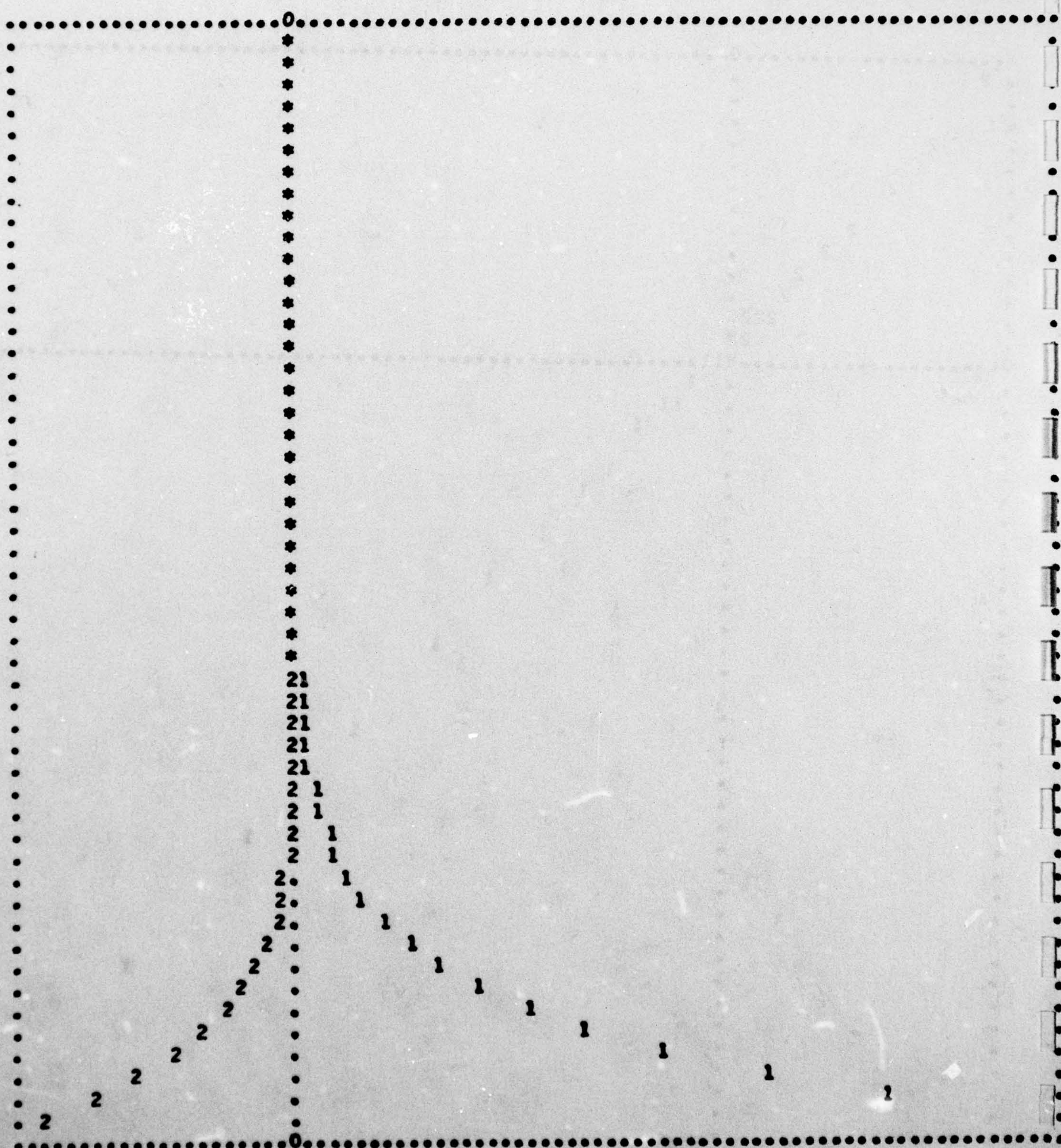


TABLE VIIc

SECOND DIMENSION

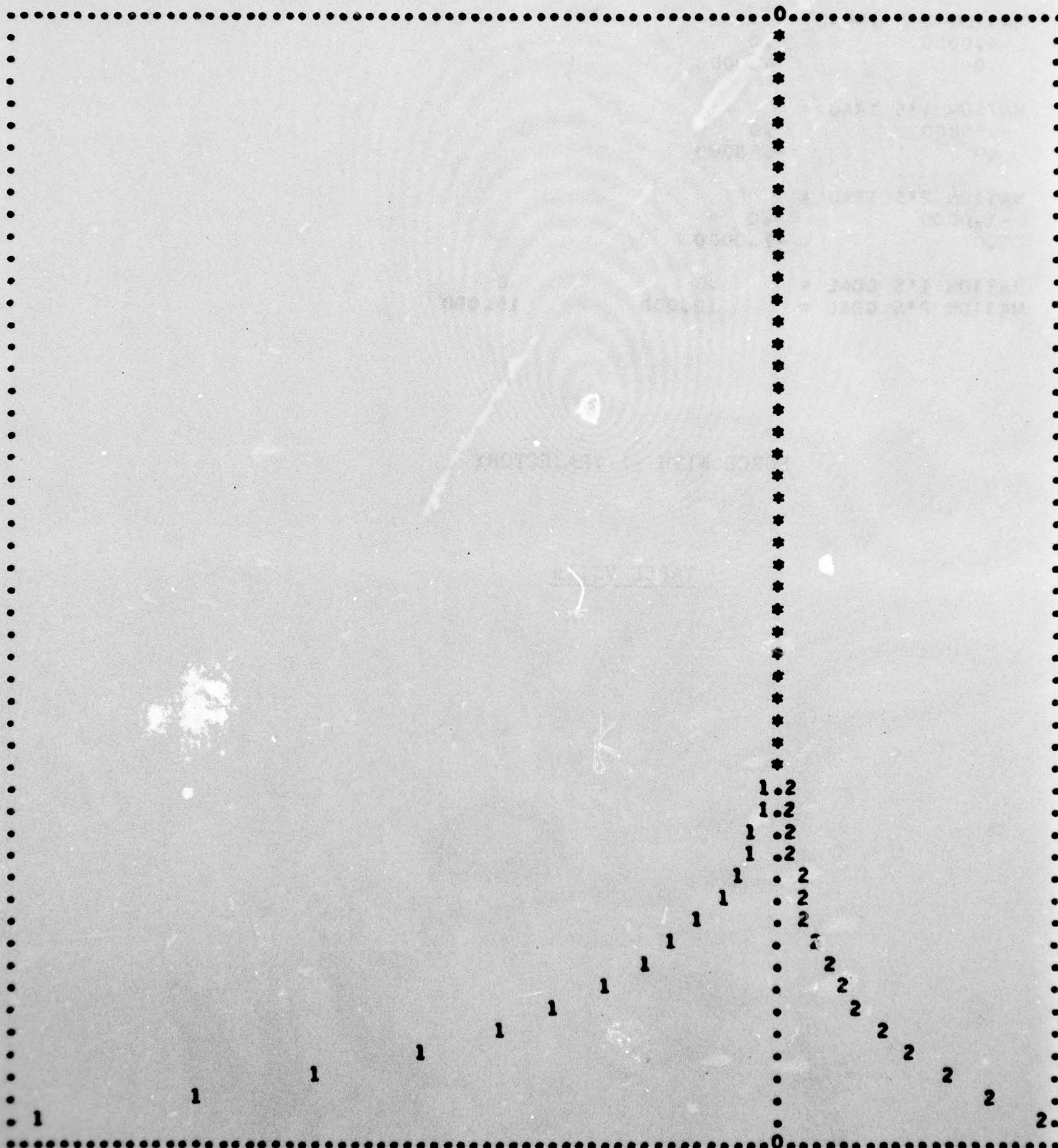


TABLE VIId

```
NATION 1'S IMPACT =
  2.0000              .0
   .0                2.0000

NATION 2'S IMPACT =
  4.0000              .0
   .0                4.0000

NATION 1'S TRAJ =
 -.50000              .0
   .0               -.50000

NATION 2'S TRAJ =
 -1.0000              .0
   .0               -1.0000

NATION 1'S GOAL =        .0              .0
NATION 2'S GOAL =       10.000          15.000
```

FORCE WITH -1 TRAJECTORY

TABLE VIIIa

XMIN = -646.25 XMAX = 115.50
YMIN = -1122.0 YMAX = 185.75
X SCALE = 9.8929 Y SCALE = 26.689

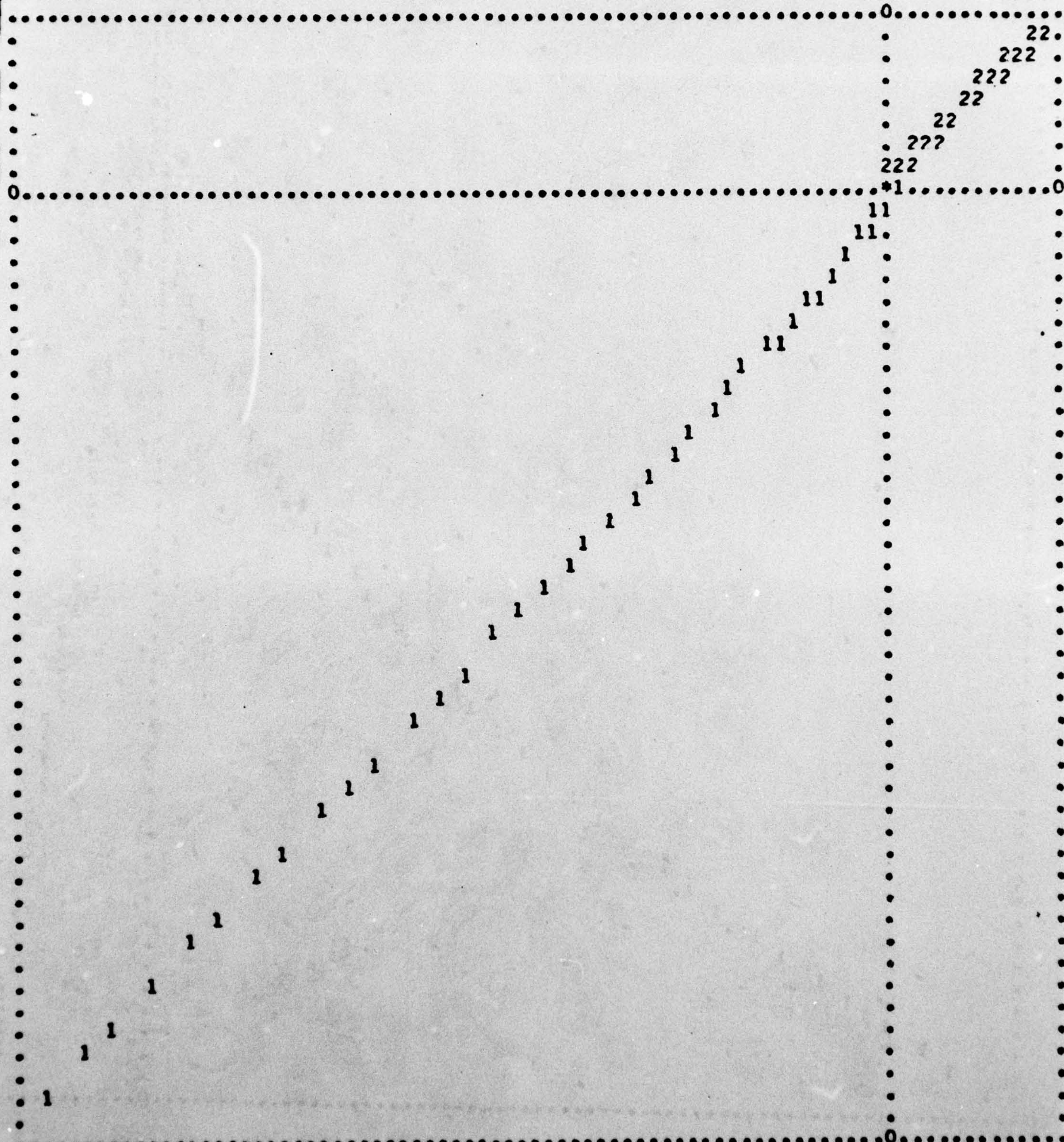


TABLE VIIIb

FIRST DIMENSION

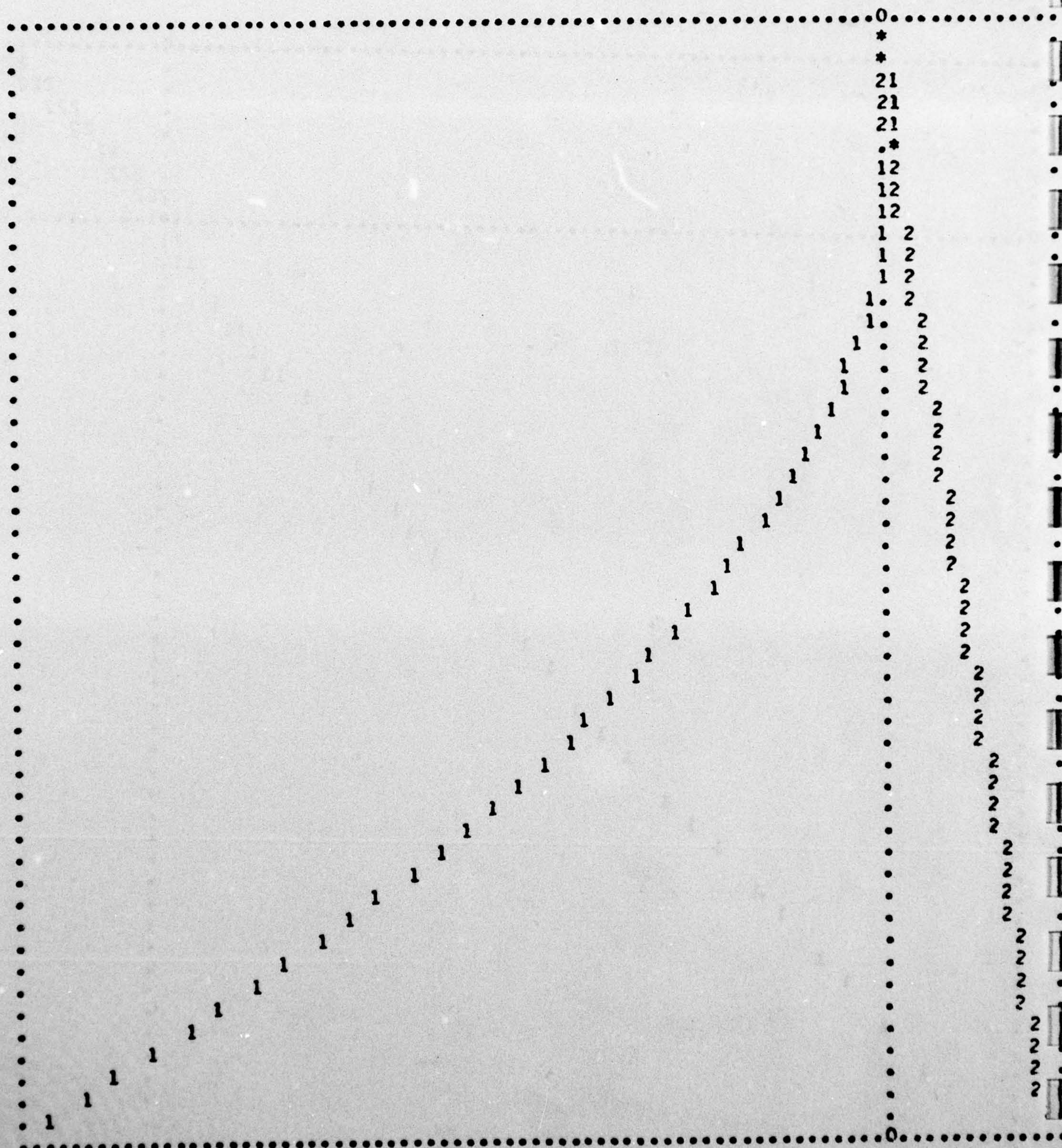


TABLE VIIIc

SECOND DIMENSION

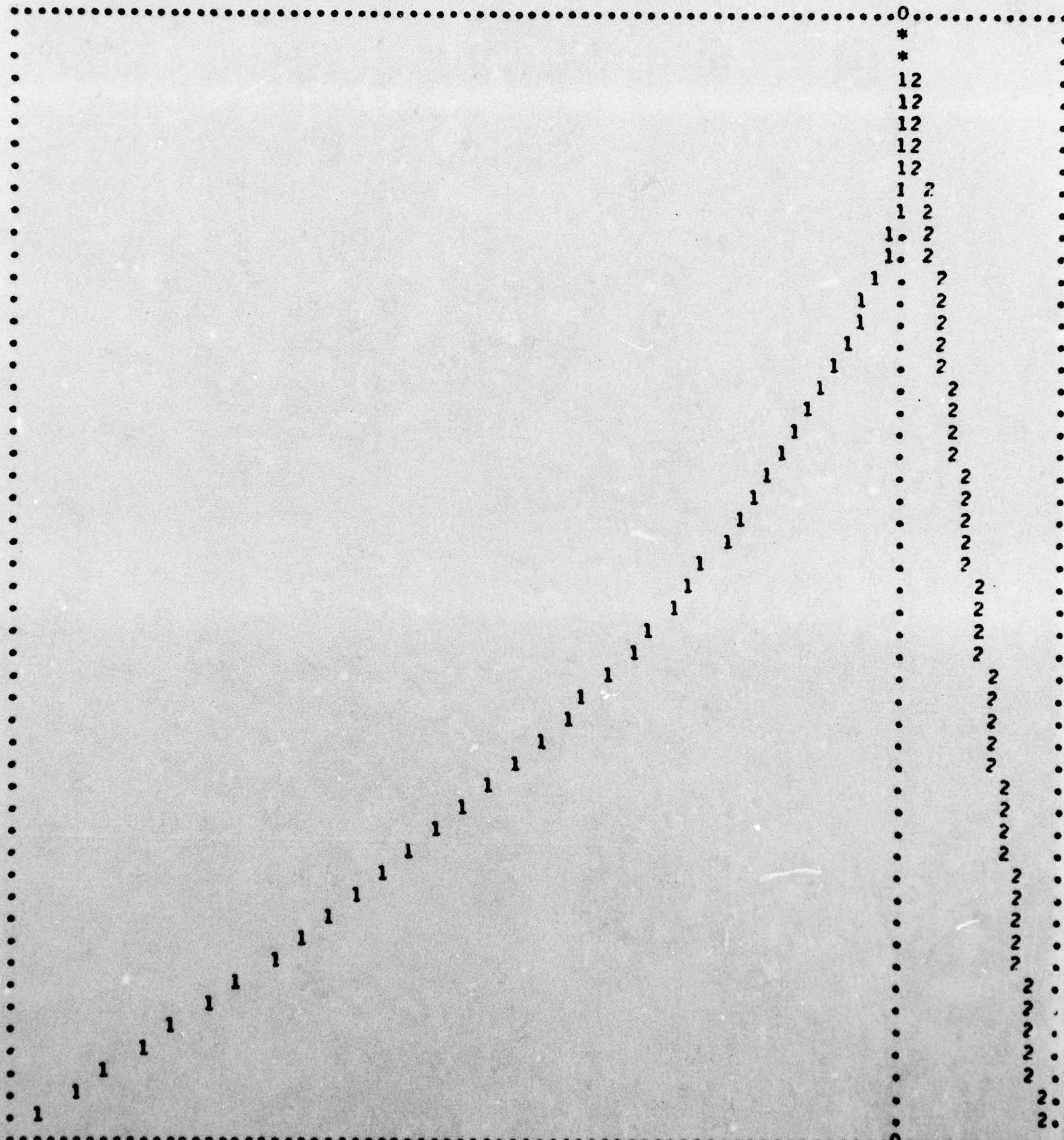


TABLE VIIId

Dimensionality and Spatial Modeling:
A Critical Assessment*

Terry F. Buss
Department of Political Science
Ohio State University

April 1974
Project Research Paper No. 22

*Prepared for delivery at the 1974 Annual Meeting of the Midwest Political Science Association. The research described in this paper was supported in part by ARPA Contract No. DAHC 15 73 C 0197.

Dimensionality and Spatial Modelling: A Critical Assessment

I. Introduction.

One important concern for any analysis of group decision-making is the general problem of constructing a procedure for passing from a set of known individual preference profiles to a pattern of social preferences subject to the fulfillment of certain specified conditions. In a classic study of the above problem, Arrow in Social Choice and Individual Values,[1] proposes certain conditions which specify desirable, while at the same time seemingly innocuous properties which every social preference ranking should satisfy. When the conditions are applied over individual preferences, the social choice is determined; but the conditions are found to be inconsistent so that no method of social choice can possibly satisfy all of the specified conditions. The social choice is shown to be either imposed or dictated. Arrow's proof demonstrates that if certain of his conditions are satisfied, the paradox of voting cannot be avoided so that given a set of transitive individual preferences, there does not result a transitive social preference.

The possibility that the paradox of voting exists such that social choices may be intransitive suggests serious problems for decision-making under majority rule, if one feels that social choice should be dependent upon the preferences of individuals in society. One approach which attempts to deal with the problem is classified under the heading "spatial models of party competition."[2] Generally, the spatial models approach seeks to identify, elucidate and analyze the conditions, necessary and/or sufficient, which would indicate the existence of a dominant position or equilibrium point which a candidate could choose in order to secure at least a tie in an election or a positive plurality if an opponent should choose any position which is not dominant. If certain of Arrow's conditions were modified by specifying other necessary and sufficient conditions which guarantee an equilibrium point in an election for a candidate, then Arrow's General Possibility Theorem might be avoided.

In the spatial approach, Arrow's conditions for rational social choice appear to be modified in two general areas: (1) the assumption of dimensionality in a multidimensional world and (2) the assumption that individuals act so as to maximize utility. Most of the additional assumptions in the spatial model, but not found in Arrow's work, are related in one way or another to these two assumptions. In this analysis the main concern will be with the assumption of dimensionality and several related assumptions; but it will also be necessary to include some mention of utility, since the two assumptions must be considered in concert in order to make sense of the spatial model.

The assumption of dimensionality is interesting in that the spatial model deals with the property of dimensionality in a world which is completely uninterpreted empirically, but which nevertheless has a highly developed formal or mathematical structure requiring the specific properties of continuity, infinity and single-peakedness over a set of alternatives ordered on a single dimension.

Using Arrow's work as a standard for the problem of rational social choice, it seems appropriate to ask of the spatial approach first, what are the major properties or characteristics of the spatial model? Second, is there an analogue in some other modelling enterprise from which inferences about the spatial model can be drawn? Third, do the properties of continuity, infinity and single-peakedness allow for a wide variety of possible, desirable qualities that a rational choice theory should satisfy? And fourth, returning to Arrow's formulation, how does the spatial model in general compare with Arrow's solution?

Since both Arrow and spatial analysts rely in part upon formal, empirical and theoretical assumptions in theory construction, it would seem appropriate to examine each along these lines. One acceptable criteria for theory evaluation[3] is: first, the theory must be examined for internal consistency by means of logical comparisons among the conclusions derived; second, the

theory must be tested for compatability with existing empirical findings or opportunities for empirical testing created by the theory; and third, the theory must be compared with competing alternatives so as to ascertain whether or not a scientific advancement has occurred.

For the most part, Arrow's formulation, demonstration and conclusions concerning the theory of social choice will be assumed as given. The reader is directed to Arrow's work Social Choice and Individual Values[4] for a complete presentation of his analysis. The mathematical notation concerning the problem of social choice will be based upon Arrow's logical formulation. The specific assumptions required by spatial analysis will be presented in Section II. For a more complete and detailed explication of these assumptions, the reader is directed to Riker and Ordeshook, An Introduction to Positive Political Theory.[5]

II. Spatial analysis: the basic model.

According to Riker and Ordeshook, a conceptualization of a citizens's most preferred candidate is best represented by a multidimensional model such that a candidate consists of a unique position on each of n finite dimensions given as a vector, $x = (x_1, x_2, \ldots, x_n)$, where x_i is the position a citizen most prefers on dimension i. In order to compare a citizens's most preferred position with a citizens's actual perception of a candidate on each dimension, a candidate's position may also be given as a vector, $\theta_j = (\theta_j^1, \theta_j^2, \ldots, \theta_j^n)$, where θ_j represents an estimate of candidate j's position on each dimension. Thus far, the analysis assumes that each dimension relevant to a citizen's vote is representable in spatial terms. Also, the spatail analysis is not sensitive to the number of relevant dimensions and their labels.

Given the vectors x_i and θ_j which summarize a citizen's preferences and perceptions, spatial analysis attempts to represent the utility a citizen expects to attain from θ_j, if a citizen prefers x. The utility function relating these two vectors is given as $U(x, \theta_j)$. Two properties are defined in terms of the above formulation: (1) if $\theta_j = x$, then $U(x, \theta_j) = \lambda$, where λ is

some maximum value; and (2) if $\theta_j \neq x$, then $U(x,\theta_j) < \lambda$. Of course, an infinite but countable, number of mathematical formulations of U satisfy the two properties above. This lack of specificity with regard to the mathematical structure allows for the inclusion of several assumptions about utility functions.

One general assumption which satisfies the two properties above is: $U(x,\theta_j)$ is concave in θ_j so that the peak or maximum value of a concave utility function is given at $\theta = x$ and the points to either side slope downward from x. This assumption implies a restriction equivalent to the property of single-peakedness, since the individual orderings may be represented on a graph such that the y-axis gives the rank order of the preference and the x-axis gives the set of alternatives with the result that any preference curve has one and only one dominant point or peak.[6] This utility function also imposes the additional requirement that the alternatives along each dimension be infinite and continuous.

The class of concave utility functions may be narrowed somewhat if only the quadratic form of the function is considered. The form is referred to as quadratic, since for one dimension the distance between $x_1-\theta_j$ is measured as the squared length between both positions. This length may also be treated as a norm. The more general expression of the above may be given as $U(x,\theta_j) = \lambda - \| x-\theta_j \|^2_A$. This expression was derived from the equation $U(x,\theta_j) = \lambda - \sum_{m=1}^{n} \sum_{k=1}^{n} a_{mk}(x_m-\theta_{jm})(x_k-\theta_{jk})$, where a_{mk} is the weighted sum and interaction between dimensions. It must be noted here that the magnitudes of each dimension depend upon the units of measurement for each dimension. Also the relative weights and possible dissimilar scales for each dimension and between each dimension are unknown. Therefore, the analysis is limited to theorems which are insensitive to the magnitude of each dimension. The quadratic form, in addition, indicates that $U(x,\theta_j)$ must be symmetric about x.

Together, concavity and its quadratic form imply that as the distance between the ideal position preferred by a citizen and the perceived position of the candidate increases, utility

decreases marginally, so that the slowest rate of decrease is experienced when θ_j and x are near oneanother and the most rapid when they are apart.

With the addition of the assumption of quasi-concavity, given as $U(x,\theta_j) = \phi\,(\lambda - \| x-\theta_j \|^2_A)$, where ϕ is any continuous monotonically increasing function, the situation in which $U(x,\theta_j)$ decreases at a slow rate when x is far from θ_j may also be accommodated within the analysis.

If either the quadratic form or the quasi-concavity ssumption are required by the spatial model, then the following restrictions are introduced into the analysis: (1) citizens may prefer different policies, but the functional forms of their utility functions are identical; (2) all citizens weight the issues in an identical fashion; (3) citizens assign the same degree of relative importance to all issues vis-a-vis oneanother; and (4) all citizens use identical scales on each dimension.

III. Physics models as analogues for spatial models.

Since the spatial model for a multidimensional world is uninterpreted in the sense that it does not specify: (1) the precise scale of measurement for each dimension, (2) the weights of each dimension with regard to others, (3) the relevant number of dimensions to be considered in the model and (4) the labels which each dimension will be assigned; it might be useful to examine the technique of dimensional analysis in other scientific enterprises, namely physics and economics, in order to assess the significance and implications of the multidimensional interpretation in the spatial model. In the process of examining the characteristics of other dimensional models, several questions are indicated and can be answered. First, what are dimensions? Second, how are they discovered? And third, how are they related to empirical, theoretical and formal aspects of the models in which they are found?

Three concepts of dimension.

When considering the concept of dimension, at least three varieties come to mind: ordinary language dimensions, geometrical dimensions and dimensions as concepts of measurement. All three

are found in or are potentially applicable to the political science enterprise, especially the spatial model approach.

The first concept of dimension, the ordinary language variety, treats the concept as being analyzable by ordinary language philosophy techniques which one might find in the works of Wittgenstein or Austin.[7] In this interpretation the concept may take on a variety of meanings for different individuals, as well as a variety of meanings for any given individual. Looking at the concept of dimension then, one finds several usages most of which may not be synonomous. For the most part, the meaning of the concept is context dependent. An example of one use of dimension would be when speaking of the complexity of some phenomenon, one might say that it had many dimensions for consideration; meaning that the phenomenon had several facets all of which are relevant in discussing the phenomenon. Another use of dimension might be discovered when contemplating the enormity of some object; in this usage, one might say, for example, that the size of a Boeing 747 is quite large in its dimensions with regard to some other object not necessarily another aircraft. To reiterate, the point being made here is that the ordinary usage of dimension is variable across contexts in which it occurs and its precision or explication is not necessarily highly developed, although its meaning is reasonably clear in every day discourse.

The second concept of dimension may be referred to as the geometical concept of dimension. One technical instance[8] of the concept may be characterized with regard to vector spaces, where a vector space is symbolized as V. The vector space V contains a set of points- vectors on which two operations are defined: vector addition and scalar multiplication. Vectors belonging to a vector space may be classified into two classes: linearly independent and linearly dependent. A linearly dependent set of vectors occurs when each vector in the set lies in the same plane and each passes through the origin. If a collection of linearly independent vectors, which are a set of vectors not in the same plane, may be represented as a linear combination of n vectors, then these vectors are a basis for V. In this

interpretation, dimension becomes dimensions of V given as n. For example, in Euclidean n-space, E^n, n represents the dimensions of E.

Notice that the geometrical interpretation of dimension differs from the ordinary language concept in that (1) it loses its ordinary language connotations becoming a technical term, (2) its meaning is precise so that agreement and disagreement about its properties and characterisitcs may be discussed in common terms, and (3) it is reasonably clear where the concept fits into the rest of mathematics. The two concepts when viewed comparatively may be seen not as correct or incorrect, but more advantageous or appropriate with regard to their use in understanding certain phenomenon.

Now, it appears that the political science notion of dimension may occur variously under both concepts. Of prime concern here would be its geometrical use, while language philosophers are concerned with the former concept. In the political science usage or application of the concept, if I understand it correctly, an interpreted mathematical structure is somehow mapped into some political phenomenon in the world or in a possible world. The procedure for mapping one structure into another may be undertaken by developing a model and mapping it into a world, or by taking some aspect of a world and mapping it into a model. Next, some numerical assignment is given to the elements of the vectors according to some rule of measurement; this is called quantification or perhaps scaling in S. S. Stevens' sense of the term.[9] The quantifed phenomenon is manipulated by any variety of techniques, in this case vector addition and scalar multiplication. A solution is obtained from these operations and this is taken to be a "description" or "explanation" of the political phenomenon.

In practice, the above use of dimension in political science and spatial modelling leads to certain paradoxes and inconsistencies which are disturbing. In the case of spatial modelling, consider first a situation wherein the following circumstances arise. Let a dimension express the quantity: government aid to education, measured on scale A. Suppose that 50% of the voters

agree and 50% disagree on the alternatives. According to the spatial model, either position is acceptable to a candidate. Next, introduce another dimension: role of government, state versus federal, with regard to social programs measured on scale B. Suppose that 100% of the voters agree with the federal support portion and 0% agree with the state support alternative. The spatial model would indicate that an optimal location occurs on the federal government alternative given at 100% agreement. Next, introduce the dimension: aid to education as scale C. Let 100% of the voters favor the position and 0% disagree. Again the equilibrium point would be at 100% agreement. One conclusion from scales A, B, and C is that scale A really is dichotomous being composed of scales B and C, where an optimal strategy suggests locating at positions which favor federal support and aid to education. Now consider a situation in which a dimension is given as federal aid to education, measured on scale A'. Suppose that the voters split on this issue 50% agreeing and 50% disagreeing, so that either the disagree or agree position would be appropriate for a candidate location. Clearly, the above conclusion does not follow with the addition of this new scale A' since one would have expected the voters to align 100% in agreement on this issue. Indeed, this phenomenon, although perhaps not manifested as clearly as above, occurs frequently in survey data analysis. The results suggest that different scales, although relating to the same quantity or relationship, may lead to alternate solutions.

Instead of viewing the above as the consequence of an inappropriate use of the concepts dimension and scale, political science suggests that there may be an error factor creeping in which alters the results. For example, some respondents may choose always to respond positively to a question no matter what it says. Usually, then, the factor is added into the model: in regression analysis, an "e" is added to the regression equation. Another frequently observed explanation, given if the error explanation is not satisfactory, would be that respondents in a survey are somehow irrational or have undeveloped belief systems, or have low centrality among attitudinal components.

Clearly, the phenomenon cannot be explained in terms of the concept of dimension being used, but must instead resort to other kinds of explanations. Given that these kinds of phenomenon arising out of the geometrical use of dimension are undesirable, perhaps it would be useful to search for another interpretation of dimension which can account for these occurrences, even if it may not in fact solve them.

This leads us to dimension as a concept of measurement.[10] In this interpretation, the analyst is concerned not only with dimension in a geometrical sense, but also with respect to measurement considerations so that the interaction of both components becomes significant.

Dimension as a concept of measurement.

In order to understand the concept of dimension, it is necessary first to understand the concept of quantity,[11] symbolized as q. Generally, quantity is expressed as a magnitude multiplied by a unit of measurement. An example of the quantity "time" would be 10 seconds, where 10 is the magnitude and seconds is the unit of measurement. Although quantities are expressed in terms of magnitude and unit, quantities are independent of both (this will be demonstrated later on in the analysis). Most sciences view the concept as a primative term in the context of justification. Quantities are classified as primary and secondary. A primary quantity is one in which the units are considered to be fundamental in the sense that they are not reducible to any other quantity. In physics, these would include mass, length and time. A secondary quantity is one which is composed of a combination of primary quantities in a functional relationship. An example would be the equation for force, where force is equal to mass times acceleration, $f = ma$. The designation of primary and secondary quantities is entirely arbitrary and depends for the most part upon the particular set of rules governing a scientific paradigm which are convenient to adopt in defining a system of measurement and upon the purpose of the analysis. In some systems, for example, the quantity force may be given as a primary quantity.

The scales used in measuring quantities are also important in understanding the concept of dimension.[12] By scale I mean (1) a rule for making numerical assignments to some phenomenon, (2) so that the same numerical assignment may be given to the same object under identical conditions and (3) so that the possibility of assigning different numbers to different things under the same conditions exists. Scales are usually given as similar and dissimilar when related to quantities. A similar set of scales suggests that all of the units used to characterize a quantity may be converted to any other unit so that an absolute ratio between two measurements remains the same regardless of a change in unit. An example for the quantity time would be 60 seconds are contained in one minute and one minute is contained in one hour. A class of dissimilar scales does not allow for conversion of one unit to another while at the same time preserving an absolute significance between two measurements. For example, time measured in seconds could not be converted to time measured in "dogs" so that the same absolute significance is preserved. This is so since dogs may be measured in terms of weight, color, volumn, number, breed, etc., which may vary across the set of all dogs so that a relationship which transforms seconds into dogs is not possible.

Dimension defined.

Keeping in mind the explication of quantity and scale above, the concept of dimension as measurement may be defined as an expression of a quantity in terms of one class of similar scales.[13]

The combination of two or more quantities by means of two or more dimensional expressions of these quantities is given as a functional relationship of the general form:

$$g = f(x_1, x_2, \ldots, x_n),$$

where q is a secondary quantity expressed as a secondary dimension, f is a function and x_1 through x_n are dimensions of quantities in the domain of the function.[14]

How dimensions are discovered.

Having defined dimensions as a concept of measurement in terms of quantity and scale, the analysis will turn next to an

explanation of how dimensions are discovered. A practical example which might be cited would be the determination of the time of swing of a simple pendulum. Potential quantities to be considered might be:

name of quantity	dimensions
time of swing	t
length of pendulum	l
mass of pendulum	m
acceleration of gravity	g
angular amplitude of swing	θ

By combining the above in the most general functional form, one obtains $t = f(l, m, g, \theta)$.[15] Clearly, all of the above dimensions in the domain of the function seem completely plausible and potentially relevant, but which ones are relevant and what is the specific form of the function combining them? In other words, how is the correct equation, $t = f(\theta)\, l/g$, which has been determined by dimensional analysis in physics discovered?

One strategy for solving the above problem would be to combine all of the above dimensions in a multitude of ways concerning every possible combination, and then test each empirically to discover an appropriate formula. Certainly this is infeasible, first, because as the number of dimensions increases the number of combinations increases also so that empirical confirmation becomes increasingly more difficult or even impossible; and second, because there is no guarantee that all of the relevant dimensions are in the list to be analyzed.

Another strategy would be to formulate a mathematical or formal structure prior to the determination of either the quantities or dimensions in the hope that the correct structure has been chosen. Of course, the strategy evidences at least two major problems: first, there are an infinite number of structures which may or may not accomodate the relevant dimensions, and second, there is no guarantee that all of the relevant dimensions may be accounted for in the structure which is being posited.

The most plausible explanation for the discovery and manipulation of dimensions- an explanation which will point up

further difficulties with the two strategies mentioned above- is one which elucidates the formal relationship between quantities dimensions and numerical laws. To begin, numerical laws may be defined as a functional relationship between two or more quantities under specified conditions which may be confronted with data. Numerical laws are expressed in functional form in a manner identical to the dimensional formulae except that the numerical law is independent of the dimensions which may define it.[16]

Since the relationship between quantities is defined as constituting a numerical law, then if quantities are independent, numerical laws must be independent also. This may be shown in three ways. First, take a quantity "time" as the phenomenon for analysis. In order to demonstrate that time is independent of the dimensions which may define it, consider at least two classes of scales which are independent of oneanother and are used to measure time: clock time and mathematical time. Clock time, expressed in seconds, is simply our everyday means of indicating time. One notion of mathematical time would be an attempt to characterize time as being a geometrical entity having length or extension. Not only does mathematical time differ in that it has extension, but within the quantity one finds that the kind of distnace function, that is, Euclidean and non-Euclidean, offers an infinite number of possible dimensions, none of which reduce to time in seconds, minutes or hours in the sense of being classes of similar scales. Clearly, if the same quantity may be expressed according to a wide variety and infinite number of independent scales, yet still refer to the same phenomenon, then the quantity must exist independently of the dimensions defining it.

Second suppose that an analyst desires to measure the quantity gravity, given as g. Through empirical testing and deductive manipulation, suppose that the secondary quantity for gravity is determined to be $m^{-1}w = g$, where w is the quantity weight and m^{-1} is the reciprocal of the quantity mass. Another analyst sees this and proposes a competing formula $g = lt^{-2}$, where l is the height an object falls and t^{-2} is the square of

the reciprocal of time during which the object falls. Both formulae are measuring the quantity gravity, yet each is completely independent and not derivable from the other in terms of the paradigm governing measurement. From this one can see that the secondary quantity gravity must be independent of the dimensions of the primary quantities which define it. And, the primary quantities are also independent of the dimensions which define them. Therefore, since a numerical law is *composed of quantities*, it too must be independent of the dimensions which define it.

And third, since the designation of primary and secondary quantities and their expression in terms of dimensions is entirely arbitrary, depending upon the purpose and (as will be discussed later) the theoretical framework of the analysis; it is not impossible for any quantity or collection of quantities to have the same dimensions. In spite of this, the quantities and numerical laws remain the same. Therefore, again the independence of quantities from dimensions which express them is indicated.

<u>Several formal implications of dimensions as viewed above</u>.

Points one through three above, suggest several important consequences for the use of dimensions in an analysis.[17] One would be that even though quantities and numerical laws are independent of the dimensions which may be used to express them and even though the specification of primary and secondary quantities is for the most part arbitrary, the choices in an analysis which manifest the character of laws and quantities determine, in part, the functional form the dimensional equation can assume. In like manner the choices with regard to classes of similar scales in which dimensional equations are represented also determine in part the formal nature of the dimensional equation. Both opportunities requiring choices, then, may be seen as limiting the formal, mathematical structures of dimensional equations.

Another consequence would be that again, since quantities are arbitrary, and quantities may be expressed in terms of

different laws and classes of similar scales, solutions to problems concerning the same phenomenon will necessarily vary with the possible result that they are contradictory or irrelevant with regard to oneanother or no comparison may even be possible. Therefore, in order to make sense of the solution to a problem, it is necessary that the prior determinants be specified in order to discover which interpretations are contradictory, irrelevant or indeterminant. If the prior determinants are not specified, then the dimensional equation provides a solution, but it will not be possible to decide for which problem it happens to be a solution. If solutions are contradictory, depending upon prior choices, then clearly the problem is highly significant, because an analyst does not know which solution to accept as apprpriate.

Yet another consequence would be that: if the specification of quantities is arbitrary, if a single quantity may be expressed in terms of alternative numerical laws and if by definition classes of similar scales are independent of other classes of similar scales, then it can be shown to follow that a dimensional equation cannot be used to deduce the formal structure of a numerical law a priori. Suppose, for example, that an analyst is given an uninterpreted dimensional equation $xy = z$. Clearly, this equation may represent any numerical law ranging from $f = ma$ to $E = mc^2$. Therefore, in general one may conclude that uninterpreted dimensional equations are of dubious value when presented devoid of the results of prior knowledge which must have preceded them or should have preceded them. The uninterpreted equation may still be of interest from a pure mathematical point of view, however. Next, consider the case wherein an interpreted model is presented a priori. Initially, it seems clear that it would be difficult or impossible to think up dimensions which do not refer to well established numerical laws. Even if the dimensions happened to be appropriate, there exists no a priori experience which would dictate their structure short of listing every structure possible or guessing about the nature of any particular one. Even if one grants that dimensions may be thought up and their structure determined, there still

appears to be no way of knowing whether all of the dimensions are included. An example of this might be that one could list all of the dimensions in the previous pendulum problem and derive its precise structure and correctly represent a law, but in order to do this one would have had to have knowledge of most all of the other laws of physics, since the dimensional equation exists with a ceteris paribus assumption with regard to these laws. In other words one would have to know that the laws of gravitational attraction, quantum mechanics, etc, should or should not be included.

A final consequence in light of the above would be that it is incorrect to consider dimensions as transformation formulae between scales.[18] This follows directly from the fact that dimensions are determined by choices of numerical laws and similar scales so that a dimension in one class of similar scales cannot be converted into the same dimension in another class of similar scales. Therefore, there exists quantities which cannot be expressed such that given magnitudes and units every dimensional representation may be converted into every other for any quantity which is designated as a primary or secondary quantity. Instead, it appears to be the case that the following characteristics are indicated: (1) transformation formulae express functional relationships between magnitudes of quantities which are uninterpreted, but which have similar or equivalent scales, (2) dimensional formulae express functional relationships between quantities being expressed as one class of independent, similar scales and magnitudes and (3) numerical laws express functional relationships between quantities, either primary or secondary, which are independent of dimensions which may be used to express them.

Spatial models: some formal implications.

In considering the spatial modelling approach in light of the formal characteristics of the analysis thus far, the following implications emerge. First, it has been noted above that our prior choices among expressions for quantities and numerical laws determines the structure of dimensional formulae. In the

spatial model, one is given a votor's vector space $x = (x_1, x_2, \ldots x_n)$ and a candidate's vector space $\theta_j = (\theta_j^1, \theta_j^2, \ldots, \theta_j^n)$ which stand for dimension in the geometrical sense of the term. Both vectors are combined into a numerical law given as $U(x, \theta_j)$, where this expression equals:

$$\lambda - \sum_{m=1}^{n} \sum_{k=1}^{n} a_{mk}(x_m - \theta_{jm})(x_k - \theta_{jk}).$$

Clearly, this expression for quantities, laws and dimensions does not in fact conform to the idea that the prior choices must act as determinants for the dimensional formula. As it now stands, the expression of the formula is true by definition since it is equivalent to the "general form" of a dimensional equation given earlier. What it does not do is specify the precise relationship which each dimension must have to every other dimension as well as to the entire set of dimensions. This of course applies here to the case of one individual and one candidate; the problem is more serious and complex when additional voters and candidates are added.

Second, the analysis has suggested that dimensions as concepts of measurement may generate problem solutions which are contradictory, irrelevant or indeterminant. In spatial modelling, consider a case wherein the same dimension has two scales which are not similar by definition, rather than derived empirically as above in the "aid to education example" and which lead to contradictory solutions. Suppose that an analyst proposes an issue dimension which has one scale given as a valence issue- "those that merely involve the linking of the parties with some condition that is positively or negatively valued by the electorate;" and the other scale as a position issue- "those that involve advocacy of government action from a set of alternatives over which a distribution of voter preferences is defined."[19] Let the valence scale and position scale be dissimilar. Further, let each scale exist such that if one is chosen the other is precluded from use. Suppose that the issue is given as a position scale and 100% of the voters agree and 0% disagree. Next, the same issue issue is given as a valence scale and 100% of the voters disagree and 0% agree. Clearly, the same dimension has one

The empirical component is perhaps best demonstrated by the nature of dimensional constants in dimensional formulae.[21] A dimensional constant is a constant which has dimensions so that a change in numerical magnitude is accompanied by a change in the size of the fundamental units involved. The obvious importance of dimensional constants may be illustrated as follows. Suppose an analyst wishes to discover the gravitational attraction between two objects. All of the important dimensions and quantities may be listed for analysis:

name of quantity	dimension
mass of first body	m_1
mass of second body	m_2
distance between bodies	r
time of revolution	t

The most general form would be given as $t = f(m_1, m_2, r)$. It is clear that on the left side of the equation one finds a unit of time, but on the right, no such dimension is possible. Therefore, one might conclude that even though all of the variables which may be varied are included, there must be something missing from the equation which when included will make the functional expression true. There are of course, an infinite number of formal expressions which may be considered, but there is no a priori way of discovering the nature of this expression. In this case, the missing element would be the gravitational costant G, given as $m^{-1}l^{3}t^{-2}$. The equation then becomes $t = G\, m_1m_2/r^2$. The inclusion of the constant significantly alters the expression. Further, the constant is not apparent in any of the quantities which are listed as relevant, and is therefore not derivable from any of the dimensions not matter which ones would be indicated. Subsequently, one may ask, how is it that the constant G comes to be included in the dimensional formula? The constant is derived by knowledge of the empirical phenomenon and from the use of certain other numerical laws which indicate that the constant is appropriate the and indeed necessitated. This illustrates that dimensional formulae are not only formal expressions, but also highly empirical in nature.

Sometimes within a dimensional analysis, the dimensional constants may be left uninterpreted. Generally, the consequences

of doing this are as follows: if the number of dimensional constants is less than the number of variables being considered in an analysis, then dimensional analysis may proceed but solutions may include an unknown constant or constants. This is not entirely undesirable, depending on the purpose of the analysis and the nature of the solution desired. If the number of constants is equal to the number of variables in an equation, then the equation can provide no information at all and dimensional analysis is impossible.

To summarize briefly, empirical components enter into an analysis in at least three places: (1) past experience of other laws, (2) use of laws in devising dimensional formulae and (3) the inclusion of dimensional constants in dimensional formulae.[22]

Several empirical implications.

The notion that dimensional equations are by necessity part empirical has several implications for dimensional models. Each of the following points may be seen to parallel or correspond closely to the implications arising out of the formal section of this analysis.

First, even though it appears that the formal or mathematical rules and structures seem to make numerical laws and dimensional equations definitional, this is not the case since it is the interpretation of the empirical phenomenon which dictates the form of the law and structure. This was evidenced by the discussion of the equations of the laws of motion and the use of dimensional constants. Therefore, just as the formal structure of numerical laws was seen as determining the dimensional equation for the law, the empirical component when interpreted may be seen as a determinant in part of the formal structure of numerical laws. Clearly, the empirical and formal determinants of numerical laws must precede the construction of a dimensional equation. If this interpretation of dimensional analysis is not followed, then dimensional formulae are not really dimensional in the sense of the concept of measurement, but are instead geometrical dimensions which are of interest in mathematics only.

Second, the nature of numerical laws suggests that the same empirical phenomenon may be interpreted in many ways according to the prior choices made in expressing them. Further, the analysis has shown that the same mathematical structure applies to many empirical interpretations of a phenomenon, but certainly not all. If this view is correct, then it follows that in order to make sense of the solutions to an analysis, the empirical and formal determinants must be specified. If this specification is not forthcoming, contradictory, irrelevant and indeterminant solutions cannot be identified. This lack of solution identification, then, would mean that we would not know what the analysis means in relation to the phenomenon.

Third, given that the empirical and the formal aspects of numerical laws are variable across interpretations, that contradictory, irrelevant and indeterminant solutions may exist and that the empirical component is a necessary element in the analysis of a phenomenon; a conclusion that may be drawn is that an uninterpreted dimensional analysis, where dimensions are geometrical entities, does not admit of the possibility of an a priori discovery or specification of numerical laws.

Spatial models: some empirical implications.

Having detailed some of the empirical implications for dimensional models, the analysis will attempt to relate these implications directly to the spatial model.

The first implication which must be considered is that dimensional formulae are in part empirical and that this empirical portion determines the formal structure of the dimensio formulae. Consider in the spatial model the mathematical property of single-peakedness and the numerical law which suggest that individuals act in such a way as to maximize utility. Other analyses have shown that single-peakedness over a set of individual preferences will guarantee a "best" social choice in a model. This remains the case no matter what one calls the orderings, that is, it does not matter whether individuals are maximizing utility or acting according to some other decision criteria. Therefore, the model gives a sufficient condition for guaranteeing an equilibrium point independent of whether

the empirical phenomenon of utility maximization for individuals exists.[23] Consequently, it appears that the addition of the assumption of utility adds nothing to the spatial model since single-peakedness already has guaranteed the results. More importantly, the empirical nature of utility maximization as viewed dimensionally exists in name only, or by definition only, and has not really determined even in part the structure of the model as the previous analysis has suggested that it should.

By not considering the empirical component in utility maximization, and by relying only upon the logical property of single-peakedness, the spatial model may be seen as highly restrictive in several potentially undesirable ways: (1) there are a good many other formal properties which also guarantee a best social choice, but are not accounted for in the spatial model. Among these would be the qualitative properties: dichotomous, echoic and antagonistic preferences; value-restricted preferences; single-caved and two-group-separated preferences; and taboo preferences.[24] All of these properties may be presented in terms of utility, but they work independently of the property as well; (2) the property of single-peakedness requires that the number of individuals concerned in social choice be odd, if a best point and not an equilibrium point is desired. Clearly, this limits the model since it cannot guarantee a best point, but merely an equilibrium point point for even numbers of individuals or free numbers, that is, numbers of individuals where oddness or evenness is irrelevant. In the above alternative properties, dichotomous, echoic and antagonistic preferences provide a best social choice when the number of individuals free;[25] (3) it is possible to find empirical examples where single-peakednes would not apply in important decision-making contexts. Take for example roll call voting in the United Nations Assembly; clearly the property of single-peakedness as a quantity common to preference orderings is not applicable in all cases; and (4) the property of single-peakedness as it stands in the spatial model can only demonstrate a sufficient condition for an equilibrium point, but not a necessary one.[26] This suggests that the property is much weaker analytically than other rational choice theories which

have specified necessary conditions for an equilibrium point as well as a "best" point.

The spatial model may also be analyzed with regard to empirical implications by examining the nature and function of dimensional constants within the dimensional model. Recall the general expression: $\lambda - \sum_{m=1}^{n} \sum_{k=1}^{n} a_{mk}(x_m - \theta_{jm})(x_k - \theta_{jk})$, where the dimensional constant a_{mk} is intended to represent the weighted sum and the interaction between each pair of dimensions. Clearly, from the above analysis, dimensional analysis in any empirical sense is impossible since the dimensions and dimensional constants are expressed in terms of unknowns. Therefore, the expression can provide us with no information about the phenomenon under analysis. The obvious rejoinder to this would be that all that needs to be accomplished is the empirical interpretation and analysis of the unknown expressions and a solution will be attained. But, this is precisely the criticism being offered in this analysis. The first important point to be noted here is that in spatial terms, the entire problem of social choice reduces to the precise expression of the a_{mk} constant. In essence then the expression of the entire mathematical structure is somewhat meaningless without information about a_{mk}. More importantly, the rejoinder does not consider the fact that the dimensional constants, in physics at least, cannot be in many cases discovered within the relevant dimensions of the phenomenon under study, but instead derive from other empirical analyses over other dimensions. This it will be recalled is the case in the expression of G the universal gravitational constant. If this view is correct, then the spatial model has really not solved the problem, but instead has shown that the constant must be determined in some other analysis.

Another implication of the empirical analysis was that since there are possiblities for contradictory, irrelevant and indeterminant solutions to dimensional problems, it is necessary for a dimensional modol to specify the exact empirical interpretations and components so that the solutionsto problems can be made sense of according to the notion of dimension as a concept of measurement. When the spatial model is considered

in light of this implication it will be necessary only to recall the example of "government aid to education" presented earlier in order to assess the consequences of empirical phenomenon for the spatial model. If the empirical components are not considered, it will be impossible for the spatial model to give a solution which can be meaningfully evaluated, since the empirical phenomenon leads to two different equilibrium points. Since one purpose of spatial modelling is to discover a unique equilibrium point, the non-empirical aspect of the model appears to be unsatisfactory.

Yet another implication involved when considering empirical aspects of a dimensional analysis is the notion that numerical laws cannot be deduced from uninterpreted mathematical structures. This conclusion implies important consequences for the analysis of empirical phenomenon by means of the spatial model. Initially, upon examining the spatial model, one finds that the numerical law for individual utility maximization over a multidimensional world is initially posited in the analysis. The law of utility maximization, although assumed, does not enjoy extensive theoretical acceptance or empirical support vis-a-vis other alternatives. Among the more prominent alternate explanations, one finds the following: (1) given the high cost of information and lack of information, individuals may seek a "satisfactory" choice, rather than some optimum one;[27] (2) individuals have a propensity to act out of interest in a game or gamesmanship so that even when alternatives are known, and probabilities are given, individuals attempt to beat the odds, thereby not maximizing utility;[28] (3) in some cases chosing one's most preferred alternative in a voting situation, may in a sense be wasting it, since it may not be a possible winner; whereas if a most preferred alternative is abandoned in favor of some less preferred alternative, then perhaps some gain may be achieved: this point suggests concepts such as "strategic" voting,[29] logrolling and Bayes minimax[30] strategies which not only concern some maximum choice, but also the notion of a minimum, as well as positions in between; (4) some individuals may not vote for utility on an individual level, but instead out of altruistic motives; (5)

it is frequently the case that individuals possess little information about politics, and vote out of an interest in citizen duty rather that utility maximization;[31] (6) it is not clear how utility would relate to undeveloped belief systems in which their exist no opinions and non-attitudes,[32] since information appears to be a necessary condition for expression of an individual's position on a set of dimensions; and (7) for a person to have an optimum choice with a subsequent ordering should not depend upon the order in which the choices are presented, and the ordering should not change when the order in which the alternatives are presented changes without some genuine attitude change, empirically, this seems for some individuals not to be the case.[33]

From the above presentation the analysis has suggested with regard to utility maximization, that there is substantial evidence that the phenomenon may not be especially warranted in many decision-making contexts. Combining this notion with the previous conclusions that the formal structure for utility maximization is unknown, there are a multitudinous variety of ways in which any law could be expressed, some of which may be mutually exclusive; and the nature of laws and quantities may lead to solutions which are contradictory, irrelevant or indeterminant; it seems clear that the possibiltiy for deducing numerical laws is at worst impossible and at best extremely fortuitous.

Spatial modelling: can it be justified?

Thus far, the formal and empirical components of dimensional models in general, have serious implications for the spatial model approach. Perhaps the polemics in this regard may be presented as follows: if the analysis is correct in asserting that formal and empirical quantities and numerical laws must exist and must be developed in order to derive a dimensional equation and if the converse is not correct, then the spatial model cannot be developed a priori. If it cannot be developed a priori, then it cannot be used to discover laws, in this case utility maximization in a multidimensional world. Instead, it appears to remain entirely definitional. The spatial analyst

might object that although the spatial model is uninterpreted, it may at some time, using the given structure, be made interpreted and subsequently tested empirically. But, the problem with this rejoinder is evident: if one needs to interpret a structure, map it into some empirical representation of a phenomenon and test it empirically, then the spatial model appears to necessitate an additional, yet unrequired step. This may be shown by observing that if the empirical phenomenon is well enough understood to be cast in dimensional terms, it must be well enough understood to be cast in terms of quantities and numerical laws. Since dimensional analysis is an analysis of an analysis, a dimensional interpretation derives also from this empirical investigation. The extra step occurs in that this derived dimensional analysis msut be compared with the posited a priori model. Clearly, if an analyst has a "properly" derived dimensional model, it would not be especially productive to have an a priori one also. Furthermore, the complexity of the simple physics problems like the pendulum problem above, suggest that the possibility of attaining a derived and an a priori model which are identical is not high.

Spatial modelling: the problem of continuity, infinity and constraints.

Thus far the analysis has discussed some of the apparent consequences- formal and empirical- when developing an uninterpreted dimensional model prior to developing its antecedents. There exists another problem of an opposite nature, when one examines the highly specific mathematical assumptions necessary to construct the dimensional structure of the spatial mdoel. The properties of continuity, infinity and single-peakedness over alternatives on a dimension taken as assumptions may serve to illustrate this point.

One potential problem created by the formal assumptions of infinity and continuity over a set of individual preference orderings occurs when constraints are introduced into the spatial model[34] so that certain alternatives which may be desirable and most preferred become infeasible. A possible example of this problem would occur in the real world environment when individuals

desire that x amount of dollars be spent on a social program, but a budget constraint of x-1 dollars makes the most preferred amount x infeasible. The problem above may be characterized as follows: the assumption of single-peakedness is a sufficient condition for the existence of an equilibrium point x over the alternatives in one dimension; but if the equilibrium point x is outside the range of feasible alternatives, then one question becomes, is there some unique point in each subset of ordered alternatives which represents a best alternative or equilibrium point?

The following analysis will demonstrate that the existence of an equilibrium point over any subset of alternatives, where a constraint is imposed such that x represents only a unique solution to an unconstrained problem, may not be guaranteed. To begin, the following notation and definitions will be offered.[35] Let S be the set of all possible alternatives to be considered for social choice. And let A be any given subset of S. Next, the concept of a maximal set may be defined: for any given subset of S, the maximal set M(A) is:

$$(\forall x)\left[\left\{x \in M(A)\right\} \leftrightarrow (x \in A) \ \& \ (\forall y)\left((y \in A \rightarrow \sim(xPy))\right\}\right],$$

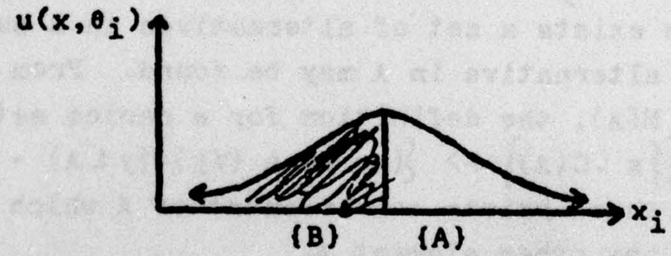
which means there exists a set of alternatives in A such that no better social alternative in A may be found. From the definition for a M(A), the definition for a choice set C(A) is given as: $(\forall x)\left[\left\{x \in C(A)\right\} \leftrightarrow \left\{(x \in A) \ \& \ (\forall y)((y \in A) - xRy)\right\}\right]$, which means that there exists some element of A which is at least as good as any other element A.

The maximal set M(A) and the choice set C(A) may be shown to be related as follows: $C(A) \subset M(A)$. If the alternatives in S are both reflexive and connected, then $C(A) = M(A)$. Of course, a unique element in C(A) would be equivalent to an equilibrium point. Using the concept of choice set, the definition of a social choice function (SCF) over the subset A may be given as a functional relation that defines a non-empty choice set for every non-empty subset of A.

A final definition which must be considered is the property of "foundedness".[36] Foundedness is a condition where for any subset A of S there does not exist an infinitely long descending

chain of the type $(\ldots x_3 R x_2 \;\&\; x_2 R x_1)$ so that the alternatives x are infinite. Using the above definitions, two analysts, Sen and Pattanaik were able to prove the following theorem:[37] a necessary and sufficient condition for R to generate a non-empty maximal set for every non-empty subset of S is that P should be founded over S. If one notes that the binary relations, R and P, are also reflexive and connected, then an additional theorem may be derived:[38] R generates a choice function over S if and only if R is reflexive and connected and P is founded over S.

Next the above analysis will be applied directly to the spatial model. Take any dimension in the spatial model which possesses the properties outlined in Section 2. Let a constraint constant be introduced into the model so that the dimension is partitioned into two intervals: $A = (x, \rightarrow)$ and $B = (\leftarrow, x]$, where the constraints constant b is given as being less than or equal to x. In effect, B will be eliminated from the set of feasible alternatives by stipulation. Graphically, the following would result, where the shaded area represents B.

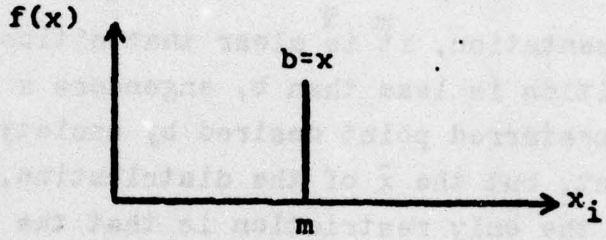


Since by construction, A has as one of its interval end-points an open-ended element x, such that for any point chosen in A there exists another point which is more preferred, no equilibrium point exists for the individual.

Since there exists the possiblity that no dominant position exists over a given subset of alternatives ordered by an individual, it remains to be seen what effect this engenders in the social choice.

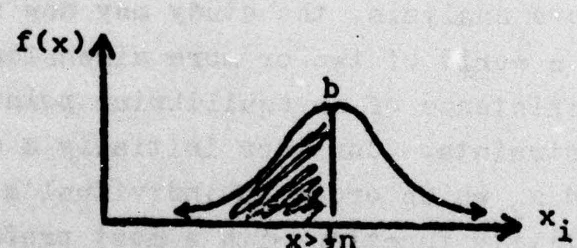
Since the constraint constant affects all citizens, some citizens or no citizen, several cases concerning the constant must be discussed.

Case one: consider a situation in which all citizens prefer the same alternative as their best choice. Let the constraint constant b for each citizen equal the constraint over the social choice preference ordering so that b equals the median of the density function f(x). Graphically, this may be represented as follows:



Clearly, under the case of unanimity above, no social choice is engendered.

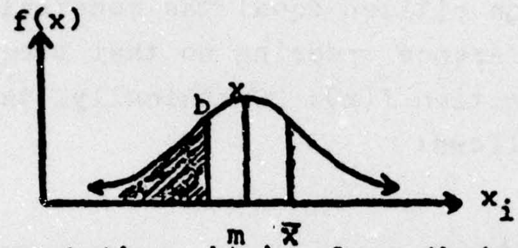
Case two: consider a situation in which a majority of citizens prefer as their best choice, alternatives which are equal to or less than the constraint constant b, so that the set of alternatives desired by the majority are infeasible. Graphically, this may be represented as follows:



In the above case, the majority, assuming that everyone votes, must prefer an alternative which is greater than b, but less than any other point. If b = x_{n+1} and descending from that point the alternatives are given as x_n, ..., x_2, x_1, then the alternatives in the feasible subset of S above are not founded. This is true since no matter what value is substituted for n, there exists at least one alternative which is more preferred. C(A) is therefore empty and no dominant point exists.

Case three: consider a situation in which a constraint constant is introduced such that the most preferred alternative for society is not eliminated as a feasible alternative, where

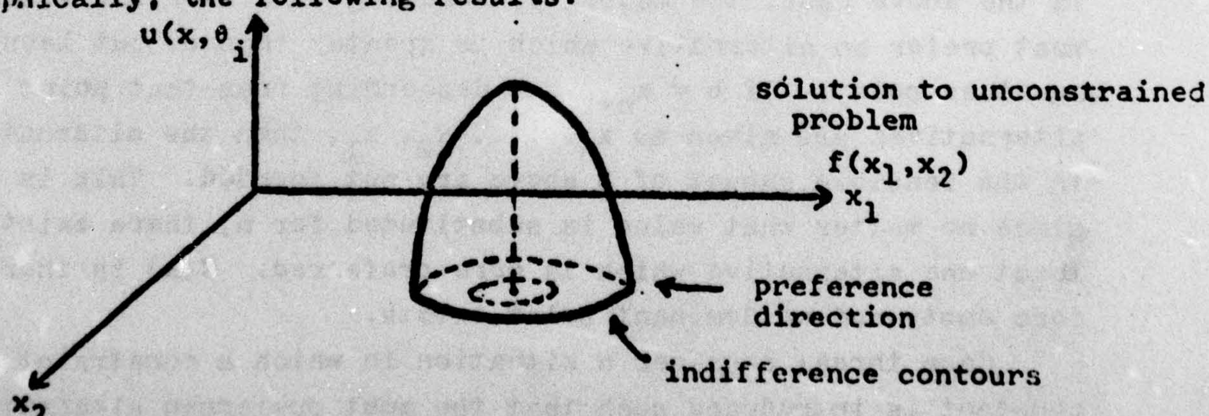
b is less than the median. Again, all citizens are assumed to vote. Graphically this may be represented as follows:



In the above representation, it is clear that citizens, whose most preferred position is less than b, engenders a situation in which the most preferred point desired by society is not the equilbrium point, but the $\bar{x}$ of the distribution, where $\bar{x} \neq M$. Also since the only restriction is that the constraint is less than b, there exists the possibility that the equilibrium point may not be unique.

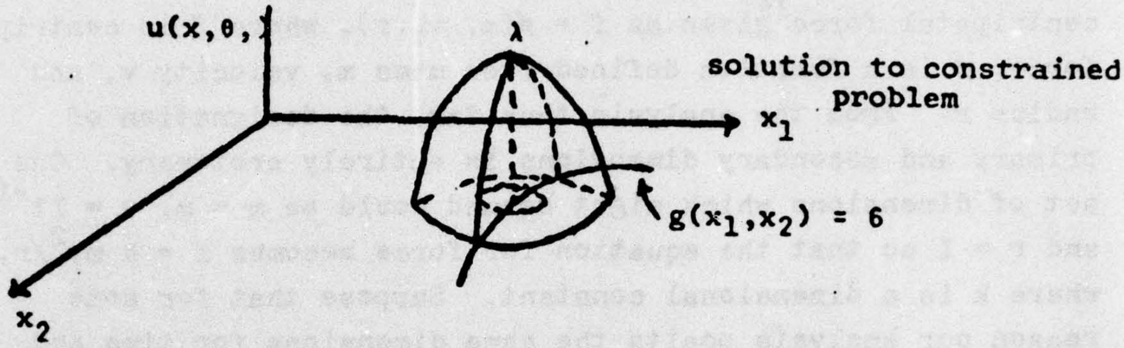
Case four: it appears that under a world of constraints, an equilibrium point only guaranteed, when for any given citizen, the constraint constant b is always unequal to x. This allows for the complete range of alternatives to be ordered over the density function f(x).

From the above analysis, the study may now proceed to a consideration of a world of two or more dimensions, in order to discover the existence of an equilibrium point under the existence of constraints. Consider initially a world of two dimensions x_1 and x_2 which order an individual's preference profile into a utility function with a most preferred position λ. Graphically, the following results:



Next, let a constraint function be introduced into the analysis so that the set of feasible alternatives is limited

by a vector in two dimensions, $g(x) = b$, where $g_1(x_1,x_2) = b_1$ and $g_2(x_1,x_2) = b_2$ such that $b = (b_1,b_2)$; and where $b = \lambda$. Also let α_i be any indifference contour not constrained by b. By construction, α_i must always be less than b and less than λ. Graphically, the following results:



In order to show that there does not exist a most preferred indifference contour for a citizen in two dimensions in the above analysis, let an indifference contour which is most preferred equal α_{n+1} and let the set of indifference contours descending from that contour equal $\alpha_n, \ldots, \alpha_2, \alpha_1$. As in the case of one dimension, no matter which contour is chosen, such that the points are elements of the real numbers, there always exists a contour which is more preferred.

It seems apparant that if the vector $x = (x_1, x_2, \ldots, x_n)$ is considered, as long as any element x_1 to x_n contains as empty choice set in one or more dimensions, then as the number of constrained dimensions increases the greater the dispersion of possiblities about a social equilibrium point.

<u>Several theoretical implications</u>.

For those schools of thought which may advocate a "narrow thesis of empiricism," that is, those who deny either the importance, necessity or existence of theoretical terms,[38] the analysis might well have ended above. In so doing, the empirical and formal components in a dimensional analysis would remain the major determining factors. In the following sections, theoretical considerations will be introduced into the analysis of dimensions as a concept of measuremnt in order to show that theoretical concerns are of considerable importance to

dimensional analysis.

If a dimensional model is to be of any value theoretically, it must be presented so that its relevance and relationship to other models, concepts and constructs within a theoretical paradigm and perhaps between theoretical paradigms is clearly established. Take for example the dimensional equation for centripetal force[39] given as $f = \phi(m, v, r)$, where f is centripetal force, ϕ is a function defined over mass m, velocity v, and radius r. From the analysis thus far, the designation of primary and secondary dimensions is entirely arbitrary. One set of dimensions which might be used would be $m = m$, $v = lt^{-1}$, and $r = l$ so that the equation for force becomes $f = k\,mv^2/r$, where k is a dimensional constant. Suppose that for some reason our analysis posits the same dimensions for time and length. Then the analysis would derive $f = ml^{-2}$, $v = l^0$, $r = l$ and it can be seen that any one of an infinite number of combinations m/r, mv/r, mv^2/r, mv^n/r would satisfy the equation. Since dimensional analysis seeks a specific solution, this solution seems to suggest that the above formula becomes somewhat meaningless for much of conventional analysis in physics so that new concepts of measurement must be developed for the entire system. From the above, then, one might conclude that theoretical import gives rise to the inclusion and/or exclusion of certain kinds of dimensions in various combinations according to the theoretical and observational nature of the quantities being analyzed. The combinations decided upon in turn determine the kind of theoretical explanation which may be offered and which may not. It, therefore, becomes important for the dimensional equation to be constructed so that its relevance to theoretical enterprises or paradigms is clearly established. If this is not accomplished, then it will be difficult or impossible to tell from which theory a model is derived or how it may be included in any theory. Ultimately, its contribution to scientific knowledge cannot be assessed, that is, it contribution toward postdiction, prediction and explanation will be unclear.

Spatial modelling: is it properly included within Arrow's paradigm?

Apparently, the spatial modelling enterprise derives at least partially from the work of Anthony Downs, but the main derivation appears to stem from Arrow's work as characterized in the introduction. It might be useful to look at both formulations to discover whether or not the spatial model interpretation may be considered to be within the same theoretical framework as that of Arrow. Taking the two approaches point by point, the following areas of divergence may be elucidated.

Initially and emphatically, Arrow prohibits the use of utility functions of any kind. This is perhaps most clearly illustrated by Arrow's Condition 3, The Independence of Irrelevant Alternatives, which explicitly eliminates utility functions, but is not used directly in the proof of the General Impossibility Theorem.[40] Arrow's reasoning in this regard may be summarized as follows:[41] (1) they are not measurable for one individual, (2) they cannot be compared across individuals, (3) there are an infinite number of possible expressions for utility in terms of functions so that choosing any one is essentially a normative judgment, and (4) they are unnecessarily restrictive with regard to additional and alternate assumptions. The spatial model, of course, assumes that the possiblity of expressing individual preferences as utility exists. Although the approach admits of the possibility of an infinite variety of functions, they limit their analysis to the class of functions listed in the explication of the spatial model. The approach also considers possible restrictions or assumptions, some of the most important of which are: (1) functional forms of utility functions for each individual are identical, (2) individuals weight dimensions in an identical fashion, (3) individuals assign the same degree of relative importance to all issues vis-a-vis oneanother.

Another topic wherein divergence is high between the two approaches would be with regard to the specific assumptions made about alternatives for social choice. In Arrow's formulation

of the problem of rational social choice, he explicitly requires that alternatives be discrete over the entire set of alternatives, as well as over any subset.[42] Further, he requires that the set of alternatives for social choice be finite.[43] Apparently, Arrow was aware of potential problems involved in dealing with continuity and infinity. The spatial model approach assumes quite the opposite, that is the spatial model works only when the alternatives ordered for an individual preference profile are assumed to be continuous as well as infinite.

Both approaches essentially require that certain limitation on the orderings of alternatives for social choice. In other words, they both define those orderings which will be admissible. For Arrow, orderings are admissible if they satisfy Axioms 1 and 2 and his five conditions. Later in his work, Arrow relaxes Condition 1 in order to admit orderings which are only single-peaked.[44] This causes the problem not to be cast in terms of social welfare functions any longer, but does provide a sufficient condition for eliminating the Impossibility Theorem. Other analysts clearly in the tradition: Sen, Pattanaik and Inada have added necessary conditions as well, merely by relaxing Condition 1. The spatial approach also assumes the property of single-peakedness, but they also add in utility maximization thereby violating Condition 3 of Arrow's work. The difference in the two approaches is clear: in the former, the relaxation of a minimal number of conditions is paramount, while in the latter, the concern is not with retaining conditions and attaining solutions within the social welfare function framework.

One of the most important characteristics of Arrow's analysis is that it applies to all decision rules meeting Arrow's five conditions such that it is completely general.[45] This means that any attempt to discover a specific rule which would avoid the Impossibility Theorem will not succeed unless the axioms and conditions are changed. The spatial model does not possess this characteristic, however, since it applies only to methods of majority decision-making which are compatable to a dimensional interpretation.

Yet another significant point of divergence between the two approaches would be the question of the possibility of a dimensional solution; this of course has been the central theme of this paper. Clearly, Arrow's formulation of the problem is entirely non-dimensional. Therefore, it is not subject to the kinds of criticism presented above, which derive from one dimensional assumption or another. In addition to not being subject to the criticisms above, Arrow's approach is not affected by the problem of accounting for a fixed structure which relates to a phenomenon which is highly variable over time.[46] Arrow's Conditions 2 and 3 account for preference orderings at any one point in time. The spatial model, however, is a fixed multidimensional structure which may deal with a highly variable phenomenon. Therefore, it would seem that the spatial model is highly restricted in that it cannot account for dimensions which are highly variable, temporary or possibly irrelevant.

A final point of divergence which encompasses all of the above criteria is that of the number of essential assumptions and restrictions required by each model. For Arrow and indeed rational choice theorists clearly in this tradition, the problem of social choice seems to be determined by positing an absolute minimum number of restrictions upon decision-making situations.[47] The spatial model as evidenced throughout this analysis requires a good deal more in the way of assumptions, and therefore, may be seen to be considerably more restricted and consequently highly limited in possibilities for application.

Given the above points of divergence, the possibility for theoretical commonality between the two may be discovered by examining the nature of the results which Arrow is trying to achieve and the results of the spatial analysts in comparison with group decision rules.[47] To begin with, group decision rules in general may be shown to be distinguishable into substs of oneanother according to the degree of restrictiveness imposed by the conditions characterizing each. The set of rules in which all others are contained is simply labeled a rule. A rule may be defined as a functional relation f the range of which

constitutes a set of binary weak preference relations defined over S and the domain of which is a class of ordered sets of binary weak preference relations defined over the set of all alternatives S. The notation for a rule is $R = f(R_1, \ldots R_n)$. Contained within the set of rules is the subset dealing only with social choice. These rules are called group decision rules. The conditions imposed upon these two kinds of rules are not stringent. For example, relations may be connected, reflexive or transitive, but they need not all occur together.

A more restricted group decision rule which requires at least two necessary conditions, reflexivity and connectedness, is the social choice function (SCF), defined briefly as a group decision rule which defines over every non-empty subset of S a non-empty choice set, C(A). Stated in less technical terms, a social choice function exists when for any subset of alternatives in S, there exists a unique alternative which is as good as or better than any other alternative in the subset. Along with the two necessary conditions above, several other conditions may be added in various combinations in order to guarantee a non-empty choice set.

The social chocie function may be further narrowed by requiring it to be a social decision function (SDF). A social decision function may be defined as a social choice function such that every social weak preference relation in its range engenders a social chocie function over S. A social decision function which has as its range a set of complete social orderings-that is, orderings which are reflexive, connected and transitive-characterizes a social welfare function (SWF).

Initially, it must be noted that the beginning definition for a rule also is a subset of other less restrictive mathematical relations, while a social welfare function is highly restricted, represents only some possible restrictive conditions, but certainly not all. The above explanation may be represented more lucidly as follows:

rules $\subset$ GDR $\subset$ SCF $\subset$ SDF $\subset$ SWF $\subset$ other rules

Arrow's theoretical world assumes as a minimum, the conditions necessary to guarantee a social welfare function. Of course, as

mentioned earlier, these conditions may lead to intranitive social preference profiles and dictatorial choices for society. The imposition of single-peakedness on Arrow's condition 1 eliminates both problems above while only restricting the range of feasible alternative orderings.

Spatial theorizing is not concerned so much with retaining Arrow's conditions as it is with representing the necessary and/or sufficient conditions for an equilibrium point to exist under majority rule in more than one dimension under the assumption that individual ordinal utility functions will lead to the generation of such a point if in fact one exists. In terms of the functions delineated above, spatial modeling seeks only a social choice function with its own set of restrictive conditions.

The initial representation of the sets of rules may be modified to show Arrow's formulation and the spatial model:

$$\text{rules} \subset \text{GDR} \subset \underset{\substack{\downarrow \\ \text{spatial} \\ \text{models}}}{\text{SCF}} \subset \text{SDF} \subset \underset{\substack{\downarrow \\ \text{Arrow}}}{\text{SWF}} \subset \text{other rules}$$

From this it is clear that with the utilization of utility functions, multidimensionality and other properties and conditions the spatial model approach cannot move up the latter of restrictive subsets to Arrow's SWF and beyond to other more restrictive rule, since this has become impossible by definition. This does not of course imply that the SCF subset of the latter of restrictiveness is somehow inferior to the SDF or SWF. It does, however, imply that both approaches being considered above are not theoretically in the same tradition.

<u>An additional theoretical implication</u>.

An important consequence of viewing quantities and numerical laws as being independent of the dimensions which may be used to express them is that the possibility for theoretical deductive analysis and manipulation may proceed even though empirical means for observation and dimensional measuremnt have not been developed. One good example of this would be the development of the theory of relativity which links Newton's laws of notion with the laws of motion for light rays. Generally, the theory

contains constructs which are as of yet unmeasurable or unobservable, but nevertheless it can explain both sets of phenomenon in a "unified"way better than any other competitor.[48] This important aspect of deductive theory seems to be most significant for doing science when the quantities and laws are interpreted; since if they are not interpreted, the resuls of any deductive manipulations will be of interest only to the mathematician or logician.

IV. Summary and conclusions.

In the above analysis, three concepts of dimension applicable to social science were considered: the ordinary language concept, geometrical concept, and dimension as a concept of measurement. Each concept was shown to have important consequences in the pursuit of scientific knowledge when compared and contrasted with the spatial modelling enterprise.

With regard to formal properties of quantities, numerical laws and dimensions, it was shown that quantities and laws determine dimensional models, but that working backwards from dimensional models in order to deduce unknown quantities and laws was not generally possible except perhaps in some fortuitous manner. This lead to the conclusion that dimensional analysis is not an a priori means for doing science, but instead, "an analysis of an analysis" which has already been completed.[49] It was also shown that according to this interpretation there exists a possibility of three kinds of solutions: contradictory, irrelevant and indeterminant. This possibility indicated the necessity of specifying interpreted dimensions so that a given solution can be evaluated as a solution to a specific problem. The anaysis of the spatial model in these terms suggested that the model could not account for the consequences and implications of dimensions as a concept of measurement.

Just as the formal antecedents of dimensional interpretations determine the formal structure of a dimensional model, the analysis also suggested that an empirical element must be considered. The empirical element was shown to be a necessary element in a dimensional model and the notion further supported

the impossibility of an a priori interpretation and the possibility of alternate solutions. Again when compared to the spatial model, the empirical section of the analysis suggested that the spatial model could not adequately account for problems arising in this area.

By combining conclusions derived from the formal and empirical sections of the analysis, the following conclusion was drawn: if the spatial model by some fortuitous circumstances can in fact acoount for the formal and empirical criticisms rendered, it still appears to be at least an extra step in gaining knowledge about a scientific interpretation of a phenomenon.

Next, the analysis attempted to show that the spatial modelling enterprise appeared to be seeking a solution or solutions to the problem of rational social choice in a manner very different from the traditional works in the field. Given that the spatial modelling enterprise was not realy seeking solutions to problems in the traditional formulation of rational social choice, it was suggested that the uninterpreted nature of the model was such that the relationship with other theoretical paradigms could not be established with the model in this form. Also closely related to this point is that the mathematical model does not specify what will and will not qualify as observation terms according to a theoretical framework. This again indicated that the model was somewhat unclear as to what it could provide solutions for with respect to specific phenomenon.

From the above summary, at least two very general conclusions might be drawn. First, perhaps when doing science, mathematics and mathematical structures should be viewed as means toward achieving explanation of a phenomenon and not as ends in themselves. This, of course, is not to say that it is improper to study mathematics as an end, since this is precisely what is done in the discipline of mathematics; instead, it is improper to study mathematics as an end in itself when doing science. And second, perhaps the problems of infinity and continuity, geometrical concepts of dimension and so on, indicate the need to develop new or alternate mathematical enterprises which are or

could be more conducive to social science explanation.

Footnotes

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45. Ibid, p. 59.

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49. Bridgman, op cit, p. 52.

Interim User's Guide for
the Oil Module

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Project Research Paper No. 23

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Introduction

This report serves as a user's manual for the oil module in its present form. Earlier Project papers (especially Research Report No. 15) have described the oil industry as it might be seen by a producing-country decision-maker. Certain aspects of the simulation module have been revised in order to reflect structural changes in country-company relationships that have occurred in the last six to nine months, but in general the context in which the module functions is accurately discussed in those papers. It will be assumed throughout the remainder of this paper that the reader is familiar with the earlier material.

The next section of this report will discuss the mechanics of how the user communicates with the module. Following that is a brief summary of the module's current structure and the relationship of that structure to the changes in country-company relations mentioned earlier. Then a treatment of the commands necessary to run the model will precede a description of a sample run of the module. In this sample run, an attempt is made to simulate the recent embargo and its aftermath (from the standpoint of Saudi Arabia).

Communicating with the Module

As mentioned in earlier Project reports, the oil module is eventually intended to send information to, and receive control from, a decision-module which will simulate the actions of decision-makers in the producing country. When the oil module becomes linked with the decision-module, the user will not communicate directly with the oil module; all communications will be handled by either the decision module or a higher level user interface module especially designed to perform input-output functions. Accordingly, some interim arrangement is necessary to facilitate user communication with the

module during the present stage of development and testing.

The PL/I language in which the oil module is written contains a feature which accomplishes this interim communications task with a minimum of input-output programming. The feature is the GET DATA statement for input, and the statement functions rather straightforwardly.

The module will notify the user that information may be entered by prompting the user in two ways. First, a short message will be printed at the user's terminal. This message will identify to the user what information may be entered at this particular time. Immediately below the message will appear a colon (occasionally a short delay will occur after the message and before the colon is printed). After the colon has been printed the user may enter information.

The format in which the information is entered is critical but simple. If one wished to set a variable (say PP, ~ posted price) equal to some value (say $2.50), one would type the following (called an assignment):

PP=2.50

Notice that no blanks appear within the assignment. Blanks may appear before an assignment, but not within one. If one wished to set a second variable (say DPIR, or desired production increase rate) to some value (say 200,000), then one would type another assignment, either on the same line as the preceding one or on the following line. If the second assignment were typed on the same line as the first it would look like this:

PP=2.50 DPIR=200000

One or more blanks must appear between assignments on the same line. If the second assignment were to be typed on the line following the first, then it would look like this:

PP=2.50 cr

DPIR=200000

NOTE: cr signifies that the user pushes the carriage return key.

In general, the user may type as many assignments as may be appropriate using either or both of the methods just described. For instance, we might have:

PP=2.50 DPIR=200000 COCI=300

Or we might have:

PP=2.50 DPIR=200000 cr

COCI=300

Or finally we could have:

PP=2.50 cr

DPIR=200000 cr

COCI=300

When the user has entered all the assignments he wishes, he then enters a <u>semicolon</u> and pushes the carriage return. The semicolon signals to the module that no more assignments are to be made and that it should return to normal processing. If the user does not wish to make <u>any</u> assignments at the time of the prompt, he should enter a semicolon and press the carriage return after the colon appears. Thus our examples would look like this:

:

PP=2.50 DPIR=200000 COCI=300; cr

Or

:

PP=2.50 DPIR=200000 cr

COCI=300; cr

Or

:

PP=2.50 (cr)

DPIR=200000 (cr)

COCI=300; (cr)

When entering information, keep in mind the following points.

1. Decimal points should be included (if appropriate) in an assignment.

2. Commas should <u>not</u> be included in an assignment (i.e., DPIR=200000, <u>not</u> DPIR=200,000). This is so even though commas are included when the values of many variables are printed by the module as output.

3. No blanks may appear within an assignment.

4. At least 1 blank must appear between assignments which appear on one line.

5. An assignment may <u>not</u> be continued from one line to the next; if the user cannot complete an assignment statement before the end of the present line, he should backspace until he gets to the blank(s) at the end of the last complete assignment and then press carriage return, typing the deleted assignment on the next line.

6. Once the user has pressed carriage return, whether after a semicolon or not, the line entered may not be changed. Check to see that all assignments on a line are correct before pressing the carriage return. (Remember that errors on a given line may be corrected by backspacing.)

7. Occasionally one may wish to enter an assignment for a variable which has letters (instead of numbers) to the right of the equals sign. This is done by enclosing the value in apostrophes and by typing the letters in upper case. Example:

CONTROL='STOP'

The user need not be concerned with the manner in which variable values are printed by the module as output. It should be noted, however, that occasionally a variable value printed as output will be printed with a semi-colon following. This is of no importance and should be ignored.

This completes the discussion of user communication with the oil module. Further information concerning specific prompting messages and appropriate user responses will be found in section IV.

Current Structure of Module

As pointed out earlier, the oil module has undergone modification, mainly because of events in the last six to nine months. In its present form, the module has three stages. The first stage generates country revenue from oil for the years 1963 through 1972. It determines the monthly revenue for any given month of that period by taking one-twelfth of the country's revenue for the appropriate year. The annual revenue figures are taken directly from Table 95 (for Saudi Arabia) of the OPEC Statistical Bulletin for 1972. The use of this method provides an easy means of providing reasonably accurate revenue information for testing other modules over this time period while explicitly avoiding any attempt to model the structural conditions in effect during that time. Overwhelming changes in country-company relationships have taken place since late 1972, with the result that the contractual structure of that period is not at all relevant for future predictions of oil production and revenues.

Beginning with January, 1973, the second stage of the oil module takes over. This stage is an attempt to model the Saudi-ARAMCO participation contract which came into force at that time. Revenues resulting from the sales of independent and sellback crude are kept distinct from tax and royalty revenues, and the Saudi government's growing control over production capacity, production level, and prices is included in the model. In both the second ("participation") and third ("current") stages, a distinction should be made between technologically constrained parameters (such as the cost of production, or the cost of a daily barrel increase in capacity) and "control" parameters, the value of which is set by actions of the producing-country government (sometimes but not always in negotiation with the other members of OPEC and/or the international majors).

The third stage models the country-company contractual relationships presently in force, and takes effect (in the module) beginning January 1974. In this third stage, the producing country government sets prices and production levels unilaterally, disregards entirely the Teheran, Geneva I, and Geneva II agreements, and determines its own share of participation. As this is written, it appears that this "current" stage is flexible enough to be useful for various alternative scenarios of future choices by the producing country government, and it also appears that there is little reason for the government to change structural relationships very greatly in the near future. The government can get virtually everything it wants by changing "control" parameters under the current arangements.

In the event that still another stage is warranted, either by further action on the part of producing country governments or because the user would like to test a set of hypothetical contractual relationships, such a stage may be written by the user and employed in the oil module. However,

this last course will be rather "messy" for the user until the Project's Terminal Monitor Program is completed, and thus no discussion will be made during the remainder of this paper of a user-written stage.

The operation of all three stages of the module may best be explained through use of an illustrative example. Accordingly, such an example is developed in the next section.

An Illustrative Run

The module is accessed at present by first logging onto the Ohio State University IRCC System 370's TSO system. Once logged on, the user should type either

```
userp 'tja010.sysproc' (cr)
```

or

```
free file(sysproc) (cr)
alloc file(sysproc) da('tja010.sysproc') (cr)
```

The system will reply with

```
READY
```

The user should respond by typing

```
$80 (cr)
```

and then, after the system responds with

```
READY
```

once again, he should type

```
runoil (cr)
```

The "$80" command will set the system's output line width to 80 columns. The "runoil" command will cause the oil module to begin execution after a (hopefully) short delay. If the system is serving a large number of time-sharing users when the "runoil" command is sent, however, the delay could be

as much as a minute or two.

The oil module will begin by prompting the user for the year and month in which he wishes the simulation to start. The prompt will appear as follows. A typical user response is indicated following the colon.

PTP OIL MODULE VERSION OF (date)

ENTER STARTING MONTH AND YEAR, FOLLOWED BY A SEMICOLON.

EXAMPLE: YEAR=1967 MONTH=8;

:

year=1972 month=1; cr

Of course, any starting month (1 through 12) is valid for the years 1963 through 1972. If, however, one wishes to have the module begin using either the "participation" or the "current" stages, one should enter either

year=1973 month=1; cr

or

year=1974 month=1; cr

respectively. These two stages presently have default initial values valid <u>only</u> for January, 1973, and January, 1974 respectively. <u>Only</u> if the user is prepared to enter the appropriate initial values for all required variables for months other than these two should he start the module in months other than these two.

The module will begin computation with the month and year given it and cycle monthly until instructed to stop. No prompting for user input will take place until the module reaches January 1973 (if it was given a starting month earlier than that). Beginning in January 1973 (when the participation stage becomes effective), the module will prompt each month for user inputs.

The "participation" stage is composed of two subroutines: the "production" subroutine and the "participation" subroutine. Equations for the "production"

subroutine are listed in Appendix I, along with descriptions of variables. This subroutine produces as output the simulated measures of production level, current production capacity, level of proved reserves, and so on. It is meant to represent the relatively fixed "physical" process of oil production.

The "participation" subroutine simulates the dominant characteristics of the participation contractual arrangements in existence between ARAMCO and Saudi Arabia in 1973. It generates as output such things as monthly revenues from independent sales of participation crude, from sellback sales of participation crude, and from tax revenues and royalties. It accepts as control inputs values for posted price, for sellback price, for independent crude sales (as a percentage of total production), and so on. Equations for the "participation" subroutine are listed in Appendix II along with definitions of variables.

Default initial values are provided for the appropriate variables for January, 1973 for both subroutines. Thus if one starts the module at that month, or is prompted when the module reaches that month, and changes no values when given the opportunity for that month, the subroutines will each begin an approximate "replication "of production and revenues in Saudi Arabia for 1973. Taking the default initial values would thus be the "normal" option for the "participation" stage. Later during the year, however, the user will be required to enter control information if he wishes to continue the "replication." The control information which he will be required to enter is much the same as that which was actually provided by the Saudi government to ARAMCO in 1973.

For the purposes of this example let us do this. Assume that the starting year and month were entered as

year=1973 month=1; CR

The module would then respond by printing

YEAR=1973 MONTH=1;

PRODUCTION SUBROUTINE PROMPT

:

The user's response would be

; cr

in order to take the default initial values. After computations were completed for production for the current month, the production subroutine would list the values of all variables computed in the production subroutine equations.

(OUTPUT APPEARS HERE....)

The module would then print

PARTICIPATION SUBROUTINE PROMPT

:

to which we have agreed to respond by typing

; cr

Once again the default initial values have been selected. And, in a manner identical to that just described for the "production" subroutine, the values of all variables computed in the "participation" subroutine equation are printed as output.

(OUTPUT APPEARS HERE...)

The module would next print

CONTROL PROMPT

:

If the user wished the module to continue running, he would enter

; cr

If, however, he wishes the module to stop running, he would enter

runswitch='STOP'; cr

The basic cycle of the oil module is, then, the following sequence of

prompts and outputs:

MONTH= YEAR= ;

PRODUCTION SUBROUTINE PROMPT

:

(user input, if any) ; cr

(PRODUCTION SUBROUTINE OUTPUT)

PARTICIPATION SUBROUTINE PROMPT

:

(user input, if any) ; cr

(PARTICIPATION SUBROUTINE OUTPUT)

CONTROL PROMPT

:

; cr (or runswitch='STOP'; cr)

During the module's cycle for the twelfth month of each year, however, yearly aggregate values for some of the variables are printed in each subroutine's output. These yearly totals are clearly identified and thus their format will not be discussed here. Appendix III lists the control inputs which must be entered by the user in order to "replicate" the actual events of 1973.

In January, 1974, the "current" stage begins. What happens inside the module is that the "participation" subroutine is replaced by the "current" subroutine. The same "production" subroutine is used in this stage. The equations and variable definitions for the "current" subroutine are given in Appendix IV, and it may be noticed that many of the variables are identical with those in the "participation" subroutine. There are, however, important differences concerning the increased unilateral control of the producing country in setting the various prices involved.

The prompts that appear for the "current" subroutine are similar to those

for the "participation" subroutine:

CURRENT SUBROUTINE PROMPT

:

It is suggested, of course, that the user accept the default initial values for the subroutine by responding with

; cr

to the January, 1974, prompt by the subroutine. Appendix V shows the appropriate control inputs by the user in order to "replicate" the first four months of 1974 and, in addition, to carry out the proposed ARAMCO capital investment program to increase capacity to 20M barrels per day by the end of 1980. Output for the "current" subroutine is similar to that of the "participation" subroutine, and includes a similar yearly summary for some variables.

Summary

The descriptions and instructions in earlier sections, when combined with the information in the various Appendices, should provide the reader with a reasonably clear understanding of how to run the oil module in its present stand-alone form. As mentioned earlier, the user module communication interface is temporary in the sense that it will be replaced when the module is joined with others in the near future. Nonetheless, the module as presently running provides a means of testing future alternative scenarios. Furthermore, to the extent that the control inputs necessary to have the module "replicate" recent history have been identified we have a basis for attempting to construct parts of the decision module; it should provide something close to these control inputs when presented with a similar context.

It was hoped that a printout from the sample run suggested in this report would be available. However, last minute computer problems prevented the inclusion of such a printout in this report.

APPENDIX I

Production Subroutine Equations, Variable Descriptions, and Initial Values

EQUATIONS:

IR=(DPIR)(COCI)

where:

IR	$	Investment Rate: the amount of capital to be invested in order to achieve a given increase in production capacity ADBR months later.
DPIR	bbl/da	Desired Production Increase Rate: the number of bbl/da production capacity is to be increased ADBR months later.
COCI	$/bbl/da	Cost of Capacity Increase: average overall cost of an increase of 1 bbl/da in production capacity.

PC=PC+EI

where:

PC	bbl/da	Production Capacity: average daily production capacity for current month.
EI	bbl/da	Effective Investment: the increase in production capacity which is to become operational during the current month (ADBR months after the money was committed for its purchase).

P=(PAPC)(PC)

where:

PAPC	dimensionless range: 0.00 to 1.00	Production as Percent of Capacity: the level of production desired by government decision-makers

expressed as a proportion of the present month's capacity.

P bbl/da — Production Rate: average actual production per day during the current month.

MP=(DAYS)(P)

where:

MP bbl — Monthly Production: actual production for the current month.

DAYS da — Number of days in the current month.

PR=(PRM)(MP)+PR

where:

PR bbl — Proved Reserves: current estimate of oil-in-place which can be recovered with existing facilities and technology and at current costs of production.

PRM dimensionless — Proved Reserves Multiplier: average ratio of net increase in proved reserves to monthly production for a given month.

ESTIMATES OR PARAMETER AND VARIABLE INITIAL VALUES FOR JANUARY 1973:

ADBR = 3 months

COCI = $300/bbl/da

DPIR = 219,000 bbl/da

PAPC = 1.0

PC = 6,575,000 bbl/da

PRM = 1.43

PR = 92,992,000 bbl

APPENDIX II

"Participation" Subroutine Equations, Variable Descriptions, and Initial Values

The following block of equations adjusts posted price according to the second Geneva agreement, and is used for the months of June through December 1973.

```
IF MONTH = 6 THEN BEGIN:
        IF MONTH = 6 THEN PP=2.898
        TESTCUR=(THISCUR-LASTCUR)/100
        IF TESTCUR>=.01 THEN CF=TESTCUR
            ELSE CF=0
        LASTCUR=THISCUR
        PP=PP+(TPOST)(CF)
    END;
```

where

TESTCUR	dimensionless	the percentage increase or decrease in the value of THISCUR (as measured on the 23rd of the previous month) compared with LASTCUR, the value of THISCUR <u>from the previous iteration</u>.
THISCUR	$	the average value of a designated group of currencies as determined on the 23rd of the previous month.
CF	dimensionless	Currency Factor: the proportion of inflation or deflation of the designated group of currencies referred to in THISCUR.

TPOST	$	The value for PP that would be in effect during a given month under the terms of the Teheran Agreement but excluding the terms of the first and second Geneva Agreements.
PP	$	Posted Price: the artificial price used in country - company relationships as a basis for determining (for tax purposes only) company "profits".

For the months January through May, the following simple assignments of posted prices which resulted from application of the Second Geneva Agreement are made:

IF MONTH=1 THEN PP=2.594

IF MONTH=5 THEN PP=2.742

For all months in 1973, the following participation equations are used to determine revenues:

TAXPAID=(PP-COP-(ROYALTY)(PP))(TAXRATE)+(ROYALTY)(PP)

where

TAXPAID	$/bbl	Tax Paid Price: the price (less production costs) paid by oil companies for their share of the oil produced.
COP	$/bbl	Cost of Production: average cost of producing one bbl of crude oil and delivering it to a tanker loading facility.
ROYALTY	dimensionless	The fixed proportion of posted price which is paid, on each company owned barrel, as a royalty to the producing-country government.
TAXRATE	dimensionless	The proportion of company "profit" (on each barrel of crude oil) which is owed to the

producing country government as a tax.

TR=(TAXPAID)(MP)(1-SHARE)

where

TR	$	Tax Revenue: the sum of all royalties and taxes paid to the producing country government for the current month's production.
SHARE	dimensionless	the ownership share (proportion) held by the producing country government under the terms of a participation agreement.

INDCRUD=(CRUDPCT)(MP)

where

CRUDPCT	dimensionless	Ratio of that portion of the current month's production which is owed by the producing country government, <u>and</u> which is to be sold independently by the government, to the current month's production.
INDCRUD	bbl	The amount (of the current month's production) which will be sold independently by the producing country government.

SELBACP=SELBACC(PP-TAXPAID)+TAXPAID

WHERE

SELBACP	$/bbl	Sell Back Price: the price at which participation oil not sold <u>independently</u> by the government is sold back to the companies.
SELBACC	dimensionless	The proportion of the difference between taxpaid cost and posted price that is added

to taxpaid cost in order to arrive at the sellback price.

SELBAC=(SELBACP)((SHARE)(MP)-INDCRUD)

where

SELBAC	$	Revenue received by the producing country government as a result of sales of its share of crude oil production by the oil companies through their regular channels. Such oil is said to be "sold back" to the companies.

INDSALE=(INCRUD)((INDPCT)(PP)-COP)

where

INDSALE	$	Net revenue received by the producing country government from its <u>independent</u> sales of crude oil.
INDPCT	dimensionless	Ratio of the price at which independent sales of crude oil are made (by the producing country government) to the posted price.

CR=INDSALE+SELBAC

where

CR	$	Crude Revenue: total revenue accruing to a producing country government through sales of crude oil it owns as a result of participation contracts.

INITIAL VALUES for parameters and variables in January 1973.

PP	=	2.594	$/bbl
COP	=	.10	$/bbl
ROYALTY	=	.125	
TAXRATE	=	.55	
SHARE	=	.25	
CRUDPCT	=	.025	
SELBACC	=	.810	
INDPCT	=	1.0	
THISCUR	=	100	
TPOST	=	2.392	
LASTCUR	=	100	

APPENDIX III

Control Inputs to "Replicate" Actual Production for 1973

MONTH	INPUTS
1	none
2	none
3	none
4	none
5	none
6	none
7	THIS=102.899
8	THISCUR=105.716
9	THISCUR=103.922
10	PP=4.126
	DPIR=0
	PAPC=.9074
11	PP=5.176
	PAPC=.6784
12	PAPC=.7165

APPENDIX IV

"Current" Subroutine Equations,

Variable Descriptions, and Initial Values

In the following equations, all variables not explicitly described are identical to the variables with the same names defined in Appendix II.

TAXPAID=(PP-COP-(ROYALTY-ROYCRUD)(PP))(TAXRATE)+(ROYALTY-ROYCRUD)(PP)

where

ROYCRUD	dimensionless	The proportion (which can never exceed ROYALTY) of the companies' share of production which the producing country government chooses to take in the form of oil instead of royalty payments.

TR=(TAXPAID)(MP)(1-SHARE-(ROYCRUD)(1-SHARE))

INDCRUD=[CRUDPCT+(1-BACKROY)(ROYCRUD)(1-SHARE)](MP)

SELBACP=(BACPCT)(PP)

where

BACPCT	dimensionless	proportion of posted price at which sell-back transactions take place.
BACKROY	dimensionless	proportion of royalty crude to be sold back to companies.

SELBAC=(SELBACP)[(SHARE+(BACKROY)(ROYCRUD)(1-SHARE))(MP)-INCRUD-(DOMUSE)(DAYS)]

where

DOMUSE	bbl/da	Domestic Usage: amount of crude oil required for daily domestic consumption during the current month.

INDSALE=(INDCRUD)((INDPCT)(PP)-COP)

CR=INDSALE+SELBAC

Initial values for "current" subroutine parameters and variables for January 1974:

PP	=	11.651	$/bbl
COP	=	.10	$/bbl
ROYALTY	=	.125	
ROYCRUD	=	0	
TAXRATE	=	.55	
SHARE	=	.25	
CRUDPCT	=	.025	
BACPCT	=	.93	
DOMUSE	=	60000	bbl/da
INDPCT	=	.93	
BACKROY	=	0	

APPENDIX V

Control Inputs to "Replicate" Actual Production for 1974

Month	INPUTS
1	DPIR=95000
	PAPC=.8136
2	PAPC=.8439
3	PAPC=.8803
4	PAPC=.9302
5	none
6	none
7	ROYALTY=.145
8	
9	
10	
11	
12	

NOTE: In order to simulate carrying out the proposed ARAMCO capital investment program,

set DPIR=147000 in OCT 75

and DPIR=0 in OCT 1980

Simulation for Policy Planning

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INTRODUCTION

An obvious objective of U.S. middle and long range planning is the development of forecasting techniques to the point where alternative policies toward specific countries can be unambiguously ranked with respect to their desirability in the light of specified national policy goals. In this paper we will describe a project which is investigating the utility of computer simulation, social science data, and the mental images of U.S. policy planners in accomplishing this objective. The project is in progress and this is a very preliminary report.

As a substantive target, U.S. relations with several Middle-Eastern oil producing countries was chosen. Specifically Iraq, Iran, Saudi Arabia, Libya and Algeria are the nations being analyzed. Several country specific modules (oil production, agriculture, human resources and national accounts, and government) are being developed to portray the dynamics within each country that might either affect or be affected by U.S. policy actions. The modules are being developed keeping in mind two sets of criteria: The first is that we want to specify those areas that policy planners feel are significantly affected by U.S. actions. The second goal is to insure that indicators are included in the simulations changes in which are likely to affect U.S. policy preferences in this region.

More specifically, we hope to:

1. Specify and inventory missions, options, desired outcomes and rationale for actions, as seen by forecasters and planners in the U.S. military.
2. Inventory and develop country level overtime relationships between key domestic characteristics such as indicators of economic development, political stability, and world political orientation.
3. Develop a computer simulation for projecting the impact of alternative U.S. actions toward these countries.
4. Combine the rationale for acting and the desired outcomes of policy planners with the simulation model in order to develop performance measures to be used with the simulation.

These objectives obviously require the study of U.S. foreign policy and, if this research is to have any positive impact upon the policy planning community, it is critical that our work be directly and continually related to their missions. While academics may possess a knowledge of analytical methods and techniques, planners have an understanding of the practical and substantive expectations that U.S. planning must take into account. Successful policy research requires both these kinds of skills and thus our research design has involved consultation with policy planners at all phases. In this way we hope to avoid some of the criticisms which have been made of applied behavioral science research. For example, it recently has been argued that a major difference between behavioral science applied research and applied research in the physical and engineering sciences is that in contrast to his colleagues in the latter areas, the behavioral scientist does most of his research in the University and does not interact in a continuous way with the potential consumers of his research.

> "The quest for solutions to social problems should involve applied research in a sense that has not usually been understood by the social scientists--a continued and close interaction between those who do the research and those who must make the decisions and policies that result in the application of research. The quest should also include rapid and continuous exchange of information and knowledge between those doing the research and those who are doing the things that research has indicated to be necessary for the solution of the problems. To achieve these interactions, it may be necessary to change... the methodology of research....."(4)

DESCRIPTION OF TASKS

Task 1: Enumeration of missions, desired outcomes, and rationale for using specific actions.

Many tools might be used to organize and to make sense of the complex environment in which U.S. foreign policy is developed. One of these tools is the model--a set of elements together with the

relations defined upon them. A model may be of many types, e.g., physical, mathematical, and mental. A mental model or image is simply an abstraction of various aspects of perpetual experience. For example, a decision maker might have a mental model of how agricultural decisions are made in Iran. He would then use this image in evaluating the potential impact of alternative U.S. policies toward that country. While mental models are frequently relied upon, there are major problems associated with this form of modeling. Decision makers often will have many different mental models, each dealing with a wide range of overlapping problems and each, frequently, inconsistant with the others. Planners are faced with difficulties in knowing which model is applicable to a specific case. Since the relationships in the mental model are generally not explicitly and clearly identified, the sources of contradiction are not immediately obvious. Policies made upon the basis of such images of the world are likely to have unintended and often undesired consequences. In addition, the lack of explicitness in mental images makes it difficult to communicate the assumptions upon which policy preferences are based. In these cases disputes about policy alternatives or outcomes may actually result from unidentified disagreement concerning the implications of actions. Perhaps more importantly from a long range planning perspective, it is difficult to manipulate the variables in mental models to assess the various impacts of U.S. strategic interactions. That is, the complexity of social phenomena makes it almost impossible to move from a vague set of assumptions about the world to the dynamic consequences these assumptions have for the impact of various policy alternatives.

Even reflecting the dynamic (i.e., overtime) behavior of a system of nations is not, of course, enough. In addition, we need to anticipate the outcome of U.S. actions. Here once again people actually involved in long range planning have vital contributions to make. All planners and policy makers routinely make estimates which can be abstracted and become the basis of an explicit and hopefully, consistent theory of how various strategic options are related to changes in exogenous conditions.

Task 2: <u>Identification of within country relationships for a specific set of variables</u>.

The amount of data or information about the conditions in specified countries currently available to political scientists and students of international relations is truly staggering. It is relatively easy today to find economic measures such as Gross National Product of almost any nation in the world. We know the amount of trade, the number of ambassadors sent abroad, or the diplomatic protests exchanged between any two nations for selected years. We have the war experience of the system as far back as 500 B.C. While we have relatively few time series data, we certainly have information about the post World War II period covering much of the national behavior and characteristics.

The task at this stage is to comb through the data currently available and to identify a set of variables and the relationships between variables which are deemed important to policy planners and long range forecasters. Certainly measures of economic development, power capability, political stability, and international political orientation are obvious candidates for a simulation model. In addition such foreign policy outputs as economic and diplomatic indicators of agreement or disagreement with major world powers, and military conflict will also be included. The exact variables will be identified in discussion with policy planners and long range forecasters.

Task 3: <u>The development of a computer simulation</u>.

Mental images of foreign policy interactions are often misleading due to the complexity of the foreign policy environment. The human mind simply is not well adapted to dealing intuitively with large numbers of variables which interact in unfamiliar (e.g.,non-linear) fashion. In fact most attempts to generate explicit models of foreign policy behavior rely on linear relations among relatively few variables (e.g., linear regression models and factor analysis). These assumptions of linearity will generally provide fairly accurate short term (several years) projections since any curve, over a short enough interval, can be approximated by a straight line. However, the longer into the future the projections are made the greater will be the likely error. In designing long term planning systems, we must be prepared to work with non-linear systems. Thus computer simulation becomes a useful technique.

Task 4: <u>Identify performance measures on the simulation</u>.

Simulating the system is not enough, however. If data based simulation is to be useful in evaluating policy impacts, it must provide answers as to which alternative strategies are likely to avoid unwanted consequences. To this end there must be be a set of performance measures defined upon the outcomes in such a way that alternative policies can be compared in terms of the desirability of their expected impacts. The performance measures of various strategies will be assessed against independent ratings of the importance of different objectives with regard to U.S. relations with other nations. The performance measures must be defined in such a way that they rank strategies according to their outcomes as anticipated in the simulation. The question then becomes; given a set of objectives with regard to a specific nation, say Brazil, what set of policy actions would best realize stated objectives given the assumed relationships between manipulable exogenous variables (that is, U.S. strategic options) for that country and the set of assumptions about both non-manipulable exogenous variables (such as the impact of Soviet or Chinese initiative toward that country) and non-manipulable endogenous variables (such as the impact of economic development).

Oftentimes, it is extremely difficult to quantify the elements in the performance index. For example, suppose the performance index include political stability, economic development, and attitudes toward the U.S. government. From a policy making perspective, the temptation here is to take the element most easily quantified (in this case probably economic development) and attempt to maximize (minimize) it with the hope the others will follow along. Oftentimes, however, yielding to this temptation can have disastrous long term consequences. In the case where, over some interval, increases in economic development lead to a decrease in stability which in turn encourages hostility toward the U.S., a policy maker who simply optimized on economic development might soon be confronted with a rapidly deteriorating situation.

It is easy to write that variables which are not easily quantified must not be excluded; it is much more difficult to recommend how to include them. Once again, working closely with policy planners and policy-makers will be helpful both in avoiding the trap of ignoring "soft" variables and in suggesting ways to index these variables.

ASSESSMENT OF MENTAL IMAGES

Since one of our objectives is to delineate the mental images of policy-makers and then to employ these images in identifying decision algorithms for foreign policy planning, we are lead to a difficult set of practical questions on how to generate responses from policy-makers which will permit us to formalize their assumptions. Not surprisingly we rapidly found that getting useful responses would not come from a straightforward question and answer routine. Those we interviewed initially were worried, for example, that we were products of the "quantitative international politics syndrome". They seemed to fear this "syndrome" as it means, from their standpoint, attempting to quantify the unquantifiable or to collect data on almost anything regardless of it's relevancy to their needs. We quickly had to make distinctions between quantitative data and the careful (e.g., mathematical) specifications of relationships.

The quantification of information about subjects of interest has long been seen as a desired goal in the study of international relations. Unfortunately, it has frequently been the case that this measurement problem has been confused with the problem of explicitly relating variables - i.e., theory development. In general, the adequate specification of a relationship cannot be done by purely empirical means. For example, Brunner[1] has demonstrated very convincingly that the data analysis strategies presently employed by political scientists (such as correlation and regression analysis) will usually not reveal the underlying structure of a system being theorized about. This will be the case regardless of whether the system behavior is analyzed cross-nationally at a point in time or individually in a time series. Thus, there are several important problems facing political scientists in the explanation of foreign policy exchanges. First, there is a very broad data analysis problem. To what extent can data-- even time series data-- be used to identify the basic structure of the model for a theory of international behavior. Since most analysis strategies cannot be used to distinguish between structure and parameters, it is the responsibility of the theorist to impose a basic structure on his observations prior to statistical manipulation.[7] Cain and Watts[2] point out, "without a theoretical framework to provide order and rationale for the larger numbers of variables, we have no way of interpreting statistical results. Regression analysis is properly used to estimate parameters for a model only when the structure of that model and the elements which make up the theory are already well specifed. This specification of the structure must precede the application of the statistical techniques."

In a somewhat novel attempt to get around this difficulty we have chosen to use policy analysts' mental images as the initial theoretical groundwork for structuring a theory. Thus we had to explain to the analysts that we were not particularly interested in collecting data and using computers to search through the numerous possible relationships between all of the variables in hopes of scoring a success in "theory hunting." Rather, we were interested in using their images to suggest particular structures and then to analyze the implications of that structure for policy decisions.

The initial interviews were primarily to introduce ourselves and our goals to policy planners and to elicit from them key concepts and some idea of the relationships between these concepts that we should be sensitive to in the development of our models. The overall intent of the interviews is to identify images in the areas of system identification, controls, and outputs. Interviews were performed in the Department of Defense's International Security Affairs and the State Department's Intelligence and Research Groups. Subsequently, interviews have been held in the Defense Department's Policy Analysis and Evaluation Agency.

Initial interviews coupled with a good deal of reading in the areas of oil production, agricultural economics and human resource economics produced initial flow diagrams such as that shown in Figure 1 for oil. These flow diagrams were used to generate responses, in terms of agreement or disagreement with the relationships demarcated, from the interviewees.

Several of those interviewed responded with helpful suggestions. Unfortunately most of those interviewed (not surprisingly) found the flow diagram difficult to work with or were reluctant to comment until they could assess what the relationships led to in terms of specific output. This has led to the interesting problem of having more difficulty identifying the system in talking with analysts than in identifying the controls they would apply or some assessment of the quality of the output of the simulation itself. Our next effort was the production of operating models in all three areas.

The operating models for the agriculture sector and the oil production cycles are now programmed. These are being used in discussions with policy planners in the State Department and Defense Department to check the plausibility of the output of the model under various parameter configurations, to elicit responses in terms of the boundaries of acceptable behavior on the part of each decision-maker, and to encourage discussion of the interaction between outputs in these areas and U.S. goals vis-a-vis each of the countries we are dealing with. There are obvious problems in relying too heavily upon a criterion. As Newell and Simon observe:[8]

> The plausibility of a fundamental hypothesis about the world is almost always time dependent. Hypotheses are seldom thought plausible when they are new and have not been widely accepted. Empirical evidence supports our hypothesis increasingly, and if the hypothesis succeeds in providing explanation for a sufficient range of phenomena it becomes more and more plausible.

While these sorts of difficulties might mitigate against using plausibility as a criterion for certain theoretical objectives, we may not want to make important policy changes until the predicted effects are, in some sense plausible.

How do we know whether policy theory is plausible? Again, one way is to ask people involved with the process. As we stated earlier, policy planners and long range forecastors have some mental images of the phenomenon which they operate and routinely make predictions regarding the consequences of actions. These should be of assistance in evaluating the plausibility of the structural relationships defined.

Several conclusions seem justified based upon our work thus far. To begin with, operating simulations do encourage policy-makers and planners to try ideas out on the simulations in terms of their impressions of plausible scenarios for each of the countries being studied. At one point in presenting an operating simulation to policy analysts in the Defense Department the simulation came to a question and answering routine which required that the operator respond with a yes or no statement. The operator was gently pushed out of the way by a General who was anxious to continue the simulation. The General remained at the controls of the terminal for approximately forty-five minutes generating scenarios which he thought were plausible and explaining what he would do were that particular configuration of outputs to occur. This strategy permits ascertaining the player's perception of critical values from the United State's position vis-a-vis the production of oil in each of these countries, the prices charged for oil, and the host country's future intentions. The simulations also let us see how the policy planner connects assistance in the human resource and agricultural area with oil production.

Another aspect of our model development has been the identification of host country decision-making. We began work in this area by requesting from the State Department country papers on each of the five countries under analysis. We also requested "five year" plans and major speeches from the embassies of each of the five countries. The response was good in each case and we had more than enough material to begin analyzing the particular goals on a country-by-country basis.[3] The speeches of major decision-makers in each of the countries were examined. The primary source of goal statements are the reports in the Foreign Broadcast Information Service Daily Report (FBIS).[9] This source has been augmented by some other primary documents and in conjunction with the five year plan financial statements, allowed us to estimate the particular directions which each country was likely to attempt to take. Country decision-making models are being developed from this material. Once they are operating we will use the systems to interact again with policy-makers in Washington. In this way we hope to make sure that the model's estimate of the likely responses of host countries is similar to the estimates that would be made by U.S. policy analysts.

The major thrust of future research will be aimed at delineating the relationship between output on a country-by-country basis in the Middle East and the operating rules the United States is likely to employ in attempt to influence the process. In this area we are taking advantage of previous government work in The Department of State.[6]

A joint EUR/INR Net Assessment Group paper attempting to assess the impact of an enlarged EC on NATO, and the implications of this impact on the effectiveness of current U.S. European defense policies projected into the period 1974-75. They introduced a new methodology of eliciting estimates of the impact of European Nations' actions upon the objectives of the U.S. The research groups also elicited statements about the likelihood of a particular objective being reached given a specified U.S. goal. The procedure was to provide matrices in which respondents were asked to identify cells in which the interception of action with an objective was thought to produce a positive, negative or no effect. They had a good deal of success identifying estimates in both cases. Matrices like the two developed in the Europolicy exercise should provide information which can structure contingency models from which to develop decision moduals.

In addition, we have a graduate student developing decision trees on Foreign Military Assistance programs from both the State and Defense Departments' perspective. He is working on published hearings before Congress and has found it possible to distinguish between State's role in deciding the desirability of assistance or sales and defense's logistics perspective on delivery and support. The bifurcation of responsibilities has lead to some very interesting scenarios.[5]

CONCLUSION

The preliminary work we have done thus far supports the position that policy planners and policy-makers

can be extremely helpful in developing simulation based forecasting systems. This helpfulness extends through all stages including identification of the system, specification of alternative policies (controls) and evaluation of the plausibility of the system response. Such helpfulness does, however, seem to depend upon fairly frequent interaction between the policy people and the researchers. Needless to say, crucial work in external validation remains.

ACKNOWLEDGMENT

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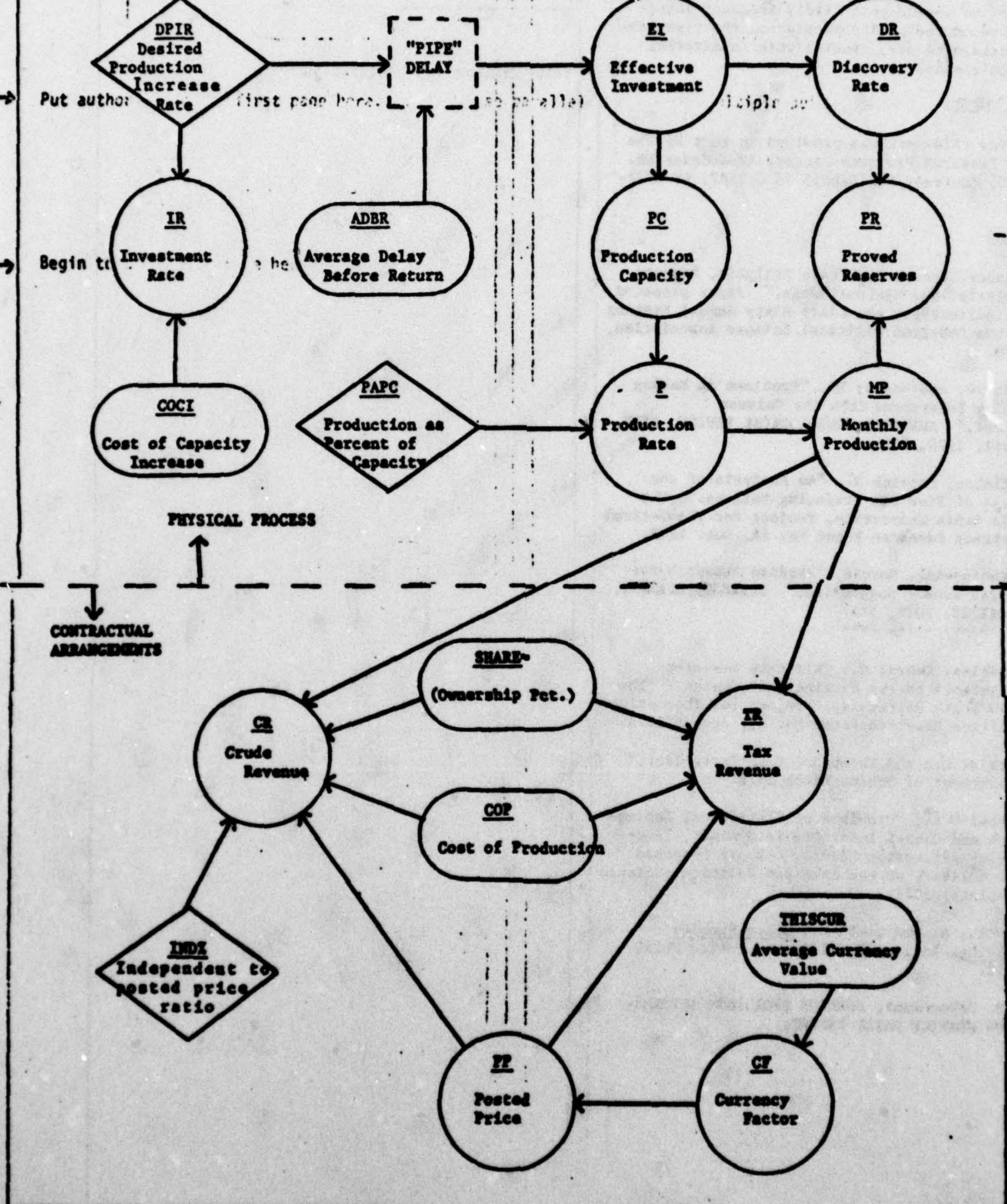
FIGURE I. CONCEPTUAL FLOWCHART OF OIL MODULE



The Inter-Nation Simulation Project:
A Methodological Appraisal*

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Definitional discussions, especially in short papers, may appear to be carried on at the expense of "doing what the paper is about." However, I prefer to view the clarification of definitional problems as initial investments which yield high (and immediate) rates of return in the form of both increased clarity and conciseness. Therefore the first section of this paper will involve stating as precisely as possible the questions to be discussed in the following sections. In addition, though no less important, the next section should serve to provide a general context in which the specific topics I will be treating become interesting.

I Problems and Context

The task of this paper, as is evident from its title is to appraise the methodological practices used in the Inter-Nation Simulation Project (INS). Such a task almost requires quoting the remarks with which R.F. Harrod (1938) began a "methodological essay:"

> Exposed as a bore the methodologist cannot take refuge behind a cloak of modesty. On the contrary, he stands forward ready by his own claim to give advice to all and sundry, to criticise the work of others, which, whether valuable or not, at least attempts to be constructive; he sets himself up as the final interpreter of the past and dictator of future efforts.

Such observations are especially important as one attempts to "assess" such a major and obviously constructive project as INS. The enormity of the technical output generated in INS

related research can be begun to be sensed as one reads the annotated bibliography of Leserman (1972). That a political scientist might undertake to critique INS from a methodological perspective is itself an indication of the successful accomplishment of Guetzkow's goal of developing a "college of simulators" within political science. Indeed, one measure of the success of an innovative project such as INS might well be the variety and quality of criticism it draws.

Since this paper involves, in part, "doing methodology," it will be useful to clarify how I will be using the term. This is especially important since many behavioral scientists appear to use the two terms "methodology" and "technique" as synonyms. I would like to distinguish the two and suggest the following. Methodology deals with questions of justification. "The method of a science is, indeed, the rationale on which it bases its acceptance or rejection of hypothesis or theories (Rudner, 1966:5)." Techniques, on the other hand, are ways of generating information which is used in evaluating a hypothesis or theory. Thus methodological positions will influence choice of technique. For example, a Hempelian scientist would probably argue that, for methodological reasons, the technique of crystal ball gazing is an inappropriate technique for the scientist. Techniques then are ways of generating evidence and methodology provides the rules according to which the evidence is admitted and, if admitted, evaluated.

The distinction I am drawing between technique and methodology is important for several reasons. First, it suggests that we can not critique the use of a particular technique without first specifying the methodological perspective from which our critique is directed. Second, and perhaps a corollary of the first, techniques which are inappropriate from one methodological perspective can become appropriate under another. Thus in appraising the techniques used in INS I must be concerned with questions of methodology choices. Indeed, as will be argued, different methodological choices may be made depending upon the purpose(s) of the investigation. Third, and perhaps least important for this paper, distinguishing technique from methodology allows the possibility that not being able to use all the techniques of, say physics, does not preclude the use of a methodology appropriate to physics. To summarize, all three reasons support the position that question of technique cannot be totally separated from the philosophical questions surrounding choice of method.

Since whatever else INS may be viewed as having done, it certainly involves the use of simulation in the investigation of international relations phenomena, it is important to define what is meant by the term simulation. In doing this, it will be helpful to discuss the related concepts of model and theory. After providing explications and definitions for these terms, I will then attempt to pose the specific questions the remainder

of this paper will address.

Harold Guetzkow has defined a simulation as

> "An operating representation in reduced and/or simplified form of relations among social units by means of symbolic and/or replicate component parts (Guetzkow, 1959, p. 184)."

The use of the adjective "social" restricts the class of simulations, but to generalize the definition one need only remove social. Indeed, this definition suggests that there are three elements which need be specified in talking about a simulation. First there is the system to be simulated, S. Second there is the representation of that system, M. Third there are the statements according to which the representation is described and/or "operates," T. These statements might be in Fortran, PL1, English, Chinese, etc. We can think S,M, and T as being sets. That is, S is the set of all referrents (or systems to be simulated); M is the set of all representations of S; and T is the set of all statements according to which the representations "operate."* Notationally we can write:

$$S: \{ s_1, s_2, \ldots s_n \}$$
$$M: \{ m_1, m_2, \ldots m_o \}$$
$$T: \{ t_1, t_2, \ldots t_p \}$$

Any specific simulation can then be identified with an ordered triple which tells us which member of S is being represented by what member of M in terms of what statements in T. These distinctions are use are useful because they point out that under

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* This discussion is based in part upon Zeigler, (1970)

the Guetzkow definition changing any one of the three elements gives us a new simulation. Thus in predicating statements of INS we must be as careful as we can in specifying each of the three components. All too often the literature seems to equate INS only with an element of M. As will be argued below, this has the implication of ignoring the impact changes in the s$\in$S might have upon the resolution of methodological and technical questions.

However before I can make these arguments I must first explicate more completely what elements of S and M look like. Elements of S are difficult to visualize in any concrete way since, by visualizing them they become represented. The elements of S are the "realities" discussed in Guetzkow (1968) or, equivalently the "reference systems" discussed in Hermann (1967, p. 220). There is no reason to require that these realities be in any sense completely known. Indeed it is precisely because they are complex (and perhaps partially unknown) that we choose to represent them as a part of a simulation effort (an elegant argument for this point is found in Naylor, 1971, pp. 2-10).

An adequate representation consists of specifying the <u>objects</u> making up the representation <u>and</u> the <u>relations</u> which are defined on these objects. That is, a representation consists of a well specified world. This notion of representation is, I believe, the one intended by Guetzkow when he writes, "Simulations in international relations attempt to represent the on-going international system or components there of, such as

world alliances, international organizations, regional trade processes, etc. (1969, 285)," and by Hermann, "A simulation or game is a partial representation of some independent system (1967, 216)".

A representation is a mathematical structure (a collection of objects and relations) and one can ask questions of possible relations between the representation and the referrent reality. For example, is there a homomorphism between s_i and m_j; an isomorphism; or, more generally, what sorts of morphisms ("generalized" mappings) might one be willing to assert to obtain between s_i and m_j. Loosely speaking these might be termed questions of external validity. Answers to these questions will require an examination of possible purposes of INS and will be considered later in this essay.

Simply representing a referrent reality (i.e., picking an $m \in M$) is not enough to provide us with a simulation. The representation will often be too complex to study directly. Therefore we will be interested in seeing what sorts of behaviors are produced (generated) by the representation. This objective requires developing a theory of the representation. This theory will take the form of statements "about" the representation. In the case of a simulation, the theory may be viewed as a set of "operating rules." The language in which these operating rules or statements are written will depend in part upon the mechanism chosen for use in the simulation. In an all machine simulation, the statements might all be in Fortran, or

Dynamo, or Simscript, etc. In a simulation combining human subjects and a computer, the operating rules may be partly in Fortran and partly in some natural language.

Once again, in any specific simulation effort, we will be led to ask questions as to possible relations to assert between elements of T and the elements of S and M. Here, however, our concern is with relations between structures (m_i and s_j) and sets of sentences (t_k). Or, more generally, one concern is with the relations between sentences and objects and relations "referred to" by those sentences. Such relations may be termed semantic (Tarski, 1944). An example of such a semantic relation is truth. Are the sentences true of the representation? Are they true of the referrent reality? Whether or not particular sentences (or sets of sentences) are accepted as true is a question of methodology. What it means to assert them to be true is a (non-trivial) question of semantics.

Thus far this discussion has been focused upon simulation. Perhaps the reader has sensed that what is involved in doing simulation is quite similar to what is involved in doing theory in general. Therefore it will be useful to quickly relate what has been done so far to the commonly encountered terms theory and model. Accomplishing this will enable me to bring in more general methodological points as this essay progresses.

The particular set of sentences or statements (i.e., $t \in T$) making up the simulation are roughly equivalent to a technical

sense of theory. They are sets of sentences which are asserted to be true of some world. Further, these sets of sentences will generally (always if an artificial programming language is used) have some preassigned logical framework or "calculus axioms" (e.g., first order predicate calculus, probability theory, etc.). These axioms allow us to investigate the implications of subsets of our set of theory statements.

A model for a theory is that "thing" which makes the sentences in a theory true. In theorizing we generally want to order or account for some aspects of a perceived reality or referrent system. Thus we represent reality in terms of some posited objects and relations. Whether or not these posited objects and relations indeed represent reality is of course in many senses moot and is certainly contingent upon both our perceptual system and our ability to make and hold to distinctions.

However, as we have seen, a collection of objects and relations is a mathematical structure and not a theory. We must write down some sentences describing (i.e., which are true of) this structure. These sentences I have termed a theory. The underlying structure I will call a model for that theory.

More specifically, a mathematical structure m is a set of elements (objects), $A = \{a_1, a_2, \ldots\}$, together with a set of relations of order i, $P_1{}^{i}1$, $P_2{}^{i}2, \ldots$, and may be expressed

$$m = \langle A; P_1{}^{i}1, P_2{}^{i}2, \ldots, P_n{}^{i}n, \ldots \rangle.$$

A formal language L in which properties of M can be expressed will consist of formulas generated by a specified set of rules, say the predicate calculus, from an alphabet consisting of relation symbols (R_1, R_2, . . .), variable symbols (x_1, x_2, . . .), connectives ($\neg$, $\vee$, $\wedge$, . . .) and quantifiers ($\forall$, $\exists$). Since functions and constants are special kinds of relations, function symbols (f_1, f_2, . . .) and constant symbols (c_1, and c_2, . . .) will also be used in L. The language L will be assumed to be first order, that is, its variables range over the elements of A (as opposed to ranging over the subsets of A, or sets of subsets, etc.). Sentences in L are formulas containing no free variables.

Let T be a set of axioms in a language L. If ϕ is a mapping of constant symbols occurring in T into the set of objects A, and also a mapping of relation symbols occurring in T into the set of relations in M, then M provides an interpretation of T under ϕ. If this interpretation results in the sentences in T being true, then M is said to satisfy T and M is a model of the axiom set T. A model for a set of axioms then, is a mathematical structure which is used to interpret the axioms in such a way that the axioms are true.*

The above discussion may appear needlessly abstract. However, its generality enables us to do several things. First it makes explicit a relationship between the simulation enter-

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* This discussion is taken from S. Thorson and J. Stever, (1974).

prise and the theory enterprise. To be specific, under these definitions, simulations become a subset of theory. This means we can employ (as is suggested in Guetzkow (1968)) the kinds of critical methodological tools used to analyze scientific theory to analyze simulation efforts such as INS.

Second, I have said that one component of any simulation is an explicit representation ($m \in M$) of a referrent system. Thus simulations belong to the subclass of theories with explicit models. By a result from model theory, we know that if an axiomatic deductive theory has a model, then it is logically consistent (i.e., it is non-contradictory). This point, while subtle, is of extreme importance. It was not until the nineteenth century, for example, that model theory was employed to show that negating the parallel lines axiom of Euclidean geometry did not lead to an inconsistency (assuming Euclidean geometry itself to be consistent).

Third, by making the representation (model) explicit, it is possible to efficiently investigate results of slightly (or grossly) perturbing the representation. This kind of sensitivity testing is very difficult to do for theories without explicit models. That INS was used in such a way is documented by the number of INS "variants" which have been produced (e.g., Bremer (1970), Smoker (1968), Abt and Gordon (1969), and Leavitt (1971)).

Having defined simulation and related this definition to that of theory and model it should be apparent that a methodological critique (under my use of methodology) of INS must address questions of the utility of INS in the development of international relations theory. To be fair to the INS project, such an appraisal must attempt to perform this evaluation within the context of the projects stated theoretical goals. Therefore, I will organize the remainder of this essay around the general problem of validity with respect to a variety of stated theoretical objectives.

II Methodological Critique

One of the great strengths of the INS project may be seen as its continuing and serious concern with problems of validation. This concern has been reflected in such papers as Alger (1963), Chadwick (1967), Crow and Noel (1965) Guetzkow (1966, 1967), Hermann (1967), Hermann and Hermann (1967), Kress (1966),McGowan (1972), Nardin and Cutler (1967), Noel (1963), Raser, Campbell,and Chadwick (1972), Robinson et al (1966), and Verba (1964). Given the methodological focus of this essay, perhaps two of the most important of these papers are Guetzkow (1968) and Hermann (1967). The Hermann paper is something of a classic and is often cited both within and outside of the behavioral sciences as a standard piece on the validation of simulations.

Hermann (1967, 217) argues that "....validity is not a singular issue..." and that "...we may more accurately refer to multiple validity issues." He then goes on to identify three components of validity issues.

> First the validity of an operating model is affected by the purpose or use for which the game or simulation has been constructed. What may be a relatively valid operating model for one objective may be strikingly unsatisfactory for another. Second, model validation can be expected to vary according to the type of validity criteria employed. Third, the validation issues will be significantly altered depending on whether human participants are introduced into the model (1967: 217).

Guetzkow (1969) identified three general purposes for simulations in the study of international relations:

> Simulations may serve in three ways as formats through which intellectuals may consolidate and use knowledge about international relations: (1) Simulations may be used as techniques for increasing the coherence within and among models, enabling scholars to assess gaps and closures in our theories; (2) Simulations may be used as constructions in terms of which empirical research may be organized, so that the validity of our assertions may be appraised; (3) Simulations may be used by members of the decision-making community in the development of policy, both as devices for making systematic critiques, through "box-scoring" its failures and successes, and as formats for the exploration of alternative plans for action (1969, 286).

These three purposes might be labelled "programmatic guide to research," "description," and "policy" respectively. That is, in the first the concern is with integrating "islands of theory" and organizing "the division of labor more coherently among the scholars working within international affairs (1969: 288)." In the second, the emphasis is upon the degree of correspondence between the representation and the reference system, i.e., description. In the third, primary focus is upon policy planning and the specification of alternative futures. Policy planning may be viewed as involving the specification of probability distributions over consequences of alternative (feasible) policies. For the purposes of this essay it will be helpful to separate the "policy" objective from what might be termed the "design" objective.

In design we are less concerned with identifying impact of alternative (presently) feasible policies and more concerned with identifying new structures for the achievement of particular goals. This notion of design is compatible with what Guetzkow (1966, 1969) has termed "constructin alternative futures". As he points out, this concern with design is one of the oldest raditions in political science. And, he argues, simulation is an important tool for the design theorist. One reason for this importance is, as we have already seen, due to the relative case with which the impact of alternative representations (models) can be investigated.

A fifth purpose for simulation (and INS in particular) which is often cited (e.g., Guetzkow (1959)) is that of education. INS has been used to teach principles of international politics in high schools, colleges and universities and various governmental bureaucracies. The few studies I have seen of the effectiveness of INS versus more traditional techniques (e.g., case studies, Robinson (1961)) have not found INS to be clearly "superior". However,given the lack of agreement on appropriate educational objectives (even within the cognitive domain) the question of the relative utility of INS type simulations for students with certain educational objectives is still an open one.

Leaving aside the educational purpose, let me next examine

INS along each of the first four objectives in somewhat more detail. These four were:

1) Programmatic guide to research
2) Description
3) Policy
4) Design

Programmatic guide to research: This purpose is potentially one of the most important for large scale simulation projects. Reasons for this importance have been brought out in another context by Allen Newell (1972) in a very interesting analysis of contemporary experimental psychology. He argues "that the two constructs that drive our current experimental style are 1) at a low level, the discovery and empirical exploration of (discrete empirical phenomena) and 2) at the middle level, the formulation of questions to be put to nature that center on the resolution of binary oppositions." This characterization could be equally well made of the contemporary empirical study of international relations. A look at recent journal articles or convention papers illustrates the concern with discrete phenomena. Further these investigations are often driven by and imbedded in such binary distinctions as internal/external, conflict/cooperation, rational/irrational, large/small, open/closed, developed/underdeveloped, etc. Will this approach to science (Newell terms it "playing twenty questions with nature") work? It may. However, "reality" may be too complex to yield to this approach. That is, we may not be able simply to add up answers to these "simple" questions to get a general theory of inter-

national relations. An alternative to playing twenty questions with nature is to construct "complete processing models," i.e., large scale simulations such as INS. Such simulations allow us to examine particular phenomena (e.g., nuclear proliferation (Brody, 1963) or public goods and alliances Burgess and Robinson (1969)) as part of a general problem structure (INS).

INS appears to have been moderately successful in terms of this objective. Numerous studies have been done using INS as a representation within which to investigate specific hypotheses. However, before we can begin to assess the utility of these studies it will be necessary to consider the related objective of description.

Description: In the introductory section of this paper I identified three elements in a simulation - referrent system (S), representation or model (M), and statements (T). The question of descriptive adequacy is a question of the S-M relationship. If both the referrent system (reality) and the model are viewed as "black boxes" with inputs and outputs, the problem of descriptive adequacy can be posed in terms of the morphism (mappings) which are preserved between S and M.

Brodbeck (1959) in her essay on models and theories suggests that there should be an isomorphism between s and m. An isomorphism is a term used to denote a mapping between two structures such that there is a one to one correspondence between the objects and relations of the first and the second structure. Yet,

as Guetzkow (1968, 207) points out, such a requirement is far too strict. I would even go beyond this and argue that such a requirement is generally undesirable. A model which was isomorphic to reality would be as intractable as reality itself. "...simulations...- like other models - are always a simplification of their reference system (Hermann, 1967: 217)." Thus we generally ask that the relation between the reference system (s) and the model (m) be a homomorphism (Guetzkow, 1968: 207). Here, at an intuitive level, rather than requiring a one-one corresponce, we allow many elements and relations of s to be mapped into those of m.

However, and to my knowledge this has not been explicitly considered in INS related research, there are a variety of morphisms which might be asserted to obtain between s and m (e.g., see Zeigler, 1970, 1971). Three such morphisms can be termed "behavior preserving," "function preserving," and "structure preserving." The weakest of these is behavior preserving. Here the concern is only that equivalent inputs in s and m produce equivalent outputs. Function preserving morphisms preserve not only input-output relations, but also internal state changes (see Arbib, 1969 for a discussion of state). Finally the most restrictive morphism - structure preserving - preserves (in addition to input-output relations and state transition functions) the manner in which these relations and functions arise out of local coordinate

functions (see Zeigler, 1970; pp 6ff). While I will not discuss structure preserving morphisms in this paper, the set theoretic view of simulation developed in the beginning of this essay is general enough to pursue such investigations.

The first two of these morphisms - behavior preserving and structure preserving - may be formalizations of what Guetzkow meant when he wrote:

> Some homomorphy may exist among outputs as well as between the very processes which result in such outputs. As we analyze the correspondences between simulations and "realities" sometimes an internal process, like the representation of the decision-making within foreign offices, helps produce an outcome of some validity, such as the constellation of internation alliances. At other times less often because of lack of appropriate research an internal process will be judged to be of some validity because the very process itself has some congruence with corresponding processes in the reference data (1968, 207).

A homomorphism among only outputs would be similar to the behavior preserving morphism, while a morphism which preserved outputs as well as "internal processes" would be a function preserving morphism.

Most of the Hermann (1967) essay seems to be concerned with identifying criteria for being able to assert a behavior preserving morphism between s and m. In the section discussing criteria for assessing the "fidelity with which a model produces aspects of reality," he suggests five validity standards:

1) Internal validity
2) Face validity
3) Variable - parameter validity
4) Event validity
5) Hypothesis validity

It will, I think, be useful to consider briefly each of these for each has implications for the method by which simulations are constructed.

"Any exogenous inputs introduced during the course of the game are held constant across all trials or runs. The unexplained variance between these intended replications would provide a measure of reliability or what Campbell (1957) calls 'internal validity.' When the structured simulation properties are held constant, the smaller the between-run variance, the greater the internal validity is assumed to be (Hermann, 1967: 220)." This notion of internal validity or reliability seems to me to be somewhat misleading. First of all note that the concern here is not with a relation between s and m. Rather an interest is purely in properties of m (or perhaps relations between m and t).

Hermann seems to be asserting that it is desirable for two runs of the same simulation with equivalent input to show equivalent output (response). With input fixed, he wants to minimize between run variance. However if the simulation is stochastic (i.e., probabilistic) either due to the explicit

use of pseudo-random number generators or due to "noise" resulting from the use of human subjects (as in INS), the response surface of the simulation will itself be a random vari?ble which will have associated with it a variance etc. One reason for constructing the simulation may be to estimate the variance associated with the response. In fact, a similar sort of argument may be found in Guetzkow)1963; 117). There is no general a priori reason to desire low between run variance.*

This criticism may appear trivial, but I think that it generalizes too much of the INS validation effort. That is, reality itself (s) is seen as highly internally valid in the Hermann sense and it therefore is expected to have very low variance. Since, by hypothesis, reality is low variance, the external validity of INS ought depend in large part upon its ability to reproduce reality. This position should become clearer as we discuss Hermann's remaining four criteria.

The second such criteria, face validity, "is a surface or initial impression of a simulation or game's realism (1967: 221)." As Hermann points out, this criterion is rather vague and is generally useful only in early stages of simulation development. However, recent efforts (Thorson and Phillips, 1974; Richardson, 1974) suggest that face validity may be

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* It might be counter argued that in the case of stochastic computer simulations the pseudo random number seed is also an input value. Therefore we would want to have low between run variance with the seed fixed. However this argument loses force when the problem of internally validating the pseudo random number generator itself is considered (see Mihram, 1972 pp 18-146).

capable of being rendered more precise by identifying the mental images of individuals who "work with" the process being represented.

The notion of variable-parameter validity "involves comparisons of the simulations's variables and parameters with their assumed counterparts in the observable universe (1967: 222)." In terms of one earlier discussion, we are concerned that the objects of m correspond to objects in s. There are at least two problems with the use of variable-parameter validity in evaluating INS. First there is the problem of aggregation. Even a complex simulation such as INS deals with variables at a highly aggregated level. Thus we might not expect the INS variables to have simple "real world counterparts." In fact, unless we are willing to assert a structure preserving morphism between INS and "reality" we <u>would</u> not expect such a correspondence. The earlier quotes from Guetzkow and Hermann suggest that no structure preserving morphism is posited.

If we are not willing to assert a simple correspondence between INS variables and those of the real world, then the problem of measurement becomes critical. Measurement theory deals with how numbers can be associated with attributes or appearances of objects in such a way that the properties of the attribute are represented as numerical properties (see Krantz et al 1971). The problems of identifying the measurement structure necessary to discuss variable-parameter validity in highly aggregated simulations have, to my knowledge, not been discussed. My

guess is that simple additive structures would not suffice. Yet without confronting the aggregation and measurement problems, it seems to me that the idea of variable-parameter validity cannot be applied to INS in any but an intuitive manner.

The fourth standard discussed by Hermann, event validity, uses " 'natural' events as criteria against which to compare outcomes occurring in the simulation (1967: 222)." For example, Hermann and Hermann (1967) used INS in an attempt to simulate the outbreak of World War I. The primary purpose of their study was to evaluate the validity of INS. "One means of investigating this question is to ascertain if a simulation produces events similar to those reported in a historical situation (1967: 401)." Thus one of the validity criteria being used was event validity.

However, for the reasons discussed under internal validity, such a use of event validity requires a commitment to a low variance external world. What if the "true" probability of the specific chain of events leading to World War I is .3? Would we then want to say that a simulation which "reliably" reproduced these events was valid? This same point is made by Verba (1964: 513) when he notes that stochastic "forces" may be operating both in the simulation and in the real world. Thus it would seem that high event-validity is neither necessary

nor sufficient to having a "valid" simulation.

The fifth and last criterion discussed by Hermann is hypothesis validity." If X is observed to bear a given relationship to Y in the observable universe, then X' should bear a corresponding relationship to Y' in a valid operating model (1967: 223)." This criterion would seem to be identical to the behavior preserving morphism discussed earlier. Again, the use of hypothesis validity requires making considerable measurement assumptions. These assumptions should be explicated.

The last four of Hermann's five criteria are all concerned with assessing the descriptive validity of simulations. Each of these criteria deals with certain posited correspondences between the refereent system and the simulation. The strongest of these correspondences would appear to be the behavior preserving morphism of hypothesis validity. I have suggested that applications of these criteria to INS may suffer from a deterministic (i.e., low variance) view of "reality" and, given the aggregated nature of INS, a too simple view of measurement.

These criticisms of the methodological assumptions underlying the evaluation of the descriptive adequacy of INS suggest why INS has not been more successful as a guide to programmatic research in the development of scientific theories of international relations. By this I do not mean, of course, that INS has not served as a catalyst for a number of very important substantive studies in international relations. It most clearly has.

However one of the luxuries of the arm chair critic is to suggest what might have been done differently. My guess is that had there been more attention paid to questions of aggregation and the related problems of measurement as the simulation was being constructed, later researchers would have found it much easier to imbed specific research questions in the general INS structure. Some work we have done at Ohio State with Forrester's World Dynamics simulation strongly indicates that once a complex simulation (especially one with significant non linearities) is constructed, it is too late to disaggregate the concepts and relations to consider specific hypothses using simple measurement structures. The tendency then is to do experiments on the simulation itself and to compare only broad behavior patterns in the simulation with those in the referrent system. For certain purposes, of course, this is perfectly adequate. However if there is a need for a simulation to serve as a "complete processing model" with which to investigate the complexity of international relations, then there is a need to consider early problems of measurement and aggregation and disaggregation. Such a purpose would seem to be what Guetzkow had in mind when he wrote that simulations "...permit the coherent amalgamation of subtheories into interactive, hosistic constructions of great complexity (1969: 206)." Further he (Guetzkow, 1968: 210) clearly recognizes the measurement problems I have outlined.

Policy: A third general objective according to which INS might be evaluated is "policy." There are numerous ways in which INS has been relevant to the policy community. These include pretesting of alternative policies on INS, providing a monitoring system, and training policy makers to be aware of the complexities underlying the impacts of policies by involving them in INS. As many of the papers coming out of the INS project have pointed out, the "validity" of INS has not been sufficiently established to rely on it very heavily in the actual policy making process. Indeed, in order to so use INS we would probably want to be able to assert at least a function preserving morphism between the simulation and the referent reality. Yet, as was argued earlier, the major validation efforts have centered upon establishing only a behavior preserving morphism (i.e., preserving input-output relationships).

With regard to the policy objective, it might have been useful to have adopted a more explicit control theoretic structure. This would have made it far easier to address questions of system optimazation using existing techniques (e.g., Box, 1954, Box and Hunter, 1958, Draper, 1962, or Gardiner et al, 1959). Had this been done it would be (at least theoretically if not computationally) possible to investigate within INS:

(a) the relative importance of alternative policies, if different environmental conditions, or if differing parametric specifications as they affect the similar response at some point T in simular time; and,

(b) that set (or combination) of policies, environmental conditions, and parametric specifications which will provide, in some sense, the optimal similar response at time T (Mihram, 1972: 402).

Answering (or even posing) such questions would probably require reconceptualizing INS in response surface terms (this might not have been all that difficult since several of the "experimental designs" employed in INS reports approached doing this). More importantly, it becomes necessary to attach some sort of objective function to the simulation so that alternative outcomes can be ordered with respect to their "desirability." The problem of identifying such functions for social systems is most difficult (for an analysis of the problem see Raiffa, 1969). *Yet if simulation is to be seriously used in* policy selection it would seem that such problems must be addressed.

<u>Design</u>: Whereas with the policy objective the concern was with identifying and implementing feasible strategies to meet some goal(s), design problems deal with identifying and describing various mechanisms for the achievement of goals. The distinction I am making here between policy and design is analogous to the distinction between the values of variables (including parameters) and their structure. Policy changes are changes in the level of variables and design changes are changes in the structure relating the variables.

Simulation is a very powerful technique (i.e., means of generating data) for the design theorist. The low cost of computer computation makes it possible to examine numbers of complex mechanisms in a variety of "environments." Moreover, the use of simulation allows the investigator to deal with non-linearities, time lagged feedback and other complications numerically where analytic solutions may either not exist or, if they exist, be beyond the symbol manipulation skills of most behavioral scientists.

Notice too, a key distinction between the policy objective and the design objective. In the case of policy the representation (i.e., $m \in M$) is taken as being fixed. Our concern is with the impact of parametric and variable value (i.e., level) changes. However, in the case of design, the representation itself is the datum and our concern is with identifying desirable (perhaps in a constrained sense) elements of M. Thus experiments designed

to optimize existing simulations will not generally serve the purpose of design as I have outlined it here (though, of course, it may give us an idea of the "best" that particular m can do).

Moreover, in the case of design, simulation can be quite properly be viewed as a data generating technique. The data generated are, of course, the performances of various m M. Under this view of design, questions of appropriate methodology again become relevant. Here, for example, we are less concerned with "correspondences" between m and s. Rather we are interested in developing preference orderings over the elements of M. As Guetzkow (1966) suggests, some of the methodological positions of "traditional" utopian thinkers may be applicable.

III Conclusion

The title notwithstanding, this essay has been more a critical review of selected aspects of the methodology of INS than it has an "appraisal." According to the O.E.D., to appraise may be rewritten "to estimate the amount, quality, or excellence of." The narrow scope of this essay does not permit an appraisal. Moreover, such a task requires a more experienced appraiser than I. However, and this may be more revealing anyway, I would be willing to bet that in the year 2000 it will be commonly acknowledged that the state of international relations theory owes a great debt to INS related activities. Already, in 1974, one cannot help but notice the number of rather sophisticated projects employing simulation (and employing it as a

matter of course). Compare this to 1964 or 1954. Had Harold Guetzkow not begun the Simulated International Processes project, a large number of us would be unable (for a wide variety of reasons) to do what we are today. Assuming that we value that which we are doing, how can we do other than consider INS a success?

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A Further Discussion of Issues in Need of Resolution:
The Notion of a Sentence Writer

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Introduction

The purposes of this report are twofold: 1) a further elaboration and integration of the general approach to the modeling of national decision processes in Anderson (1974); and 2) a fairly careful discussion of the properties and operation of one component of that general model, the observation interface. As will be discussed more fully below, the nation is conceived as an adaptive goal seeking system. The system has goals for the configuration of its external environment. Observations are taken on that environment by the observation interface. The system then takes the pictures of that environment, evaluates it with respect to the system's goals, and through a process describes below, determines actions or behavior to be emitted that will bring the environment closer to the goal state. In order for a decision system having these properties to be constructed, there must be careful explication of 1) exactly what those properties are; 2) which system parts are responsible for their production, implementation and maintenance; 3) how those system components operate; 4) structural and information requirements necessary for the operation of the components; and 5) how the system components are linked through channels of communication and control (Cf. Deutsch 1966 on communication and control and Newell's (1973b) discussion of the control structure). The answers to those five questions will represent the transformation of the general notion of an adaptive framework of national decision systems from what Simon (1973) in somewhat different context has called an ill-structured problem to the specification of a well-structured problem -- a full blown process model of the national decision making process. Until the notion

of an adaptive goal seeking national decision system can be expressed in a well-structured manner the model cannot be built. Thus it is towards the transformation of general goal seeking notions about the behavior of national decision systems into a well-structured format that the efforts of this report are aimed. As will become more apparent below, one of the advantages of the basic conceptual framework upon which efforts are focused to express in a well-structured manner is the ability of the general framework to identify separ<u>able</u> (not separate) clusters of issues. Separability does not make the specification of a well-structured problem easy; it does make it easier. The explication of the notion of the observation interface and a related conception called the sentence writer (SW) constitute the second portion of this report.

The Big Picture

The basic components of the adaptive goal seeking framework for national decision systems is illustrated in Figure I. The components are: 1) the inner environment (IE); 2) the outer environment (OE); 3) the access interface (AI); 4) the observation interface (OI); and 5) the model (or image) of the OE (M). While the framework is discussed more fully in Thorson (1971) some comments seem in order. The interpretation of this framework into national decision system terms results in the following names being assigned the basic components: 1) the inner environment is the government of a particulat nation; 2) the outerenvironment is potentially everything that is external to the governmental structure of the IE; 3) the observation interface are those portions of the bureaucracy that are responsible for the observation of the current state of the OE; 4) the access interface is composed of those components of the bureaucracy that are responsible for executing the actions that flow from the IE; and 5) the model is a shorthand term referring to how the various elements in the national bureaucracy responsible for the determination of decisions believe the OE works. It is important to note that the IE is defined strictly as the government. In contemporary theorizing in the field of international relations it is often the case that the unit of analysis is the nation, often expressed as the "political system." This view is best exemplified by the efforts of Rummel's (1971) status field theory and Singer's (1972) Correlates of War Project. The claim is not being made that the approach advocated here is strictly better than the specification of the unit of analysis as the nation. But it does seem to be the case that given the types of concerns expressed and the sort

of explanation and theoretical structure that are desired, the specification of the IE as the government is better than the specification of the IE as the nation. On the other hand, there are instances where it may be more efficient to view the unit of analysis as the nation as a whole. It is important to notice that taking the government as the unit of analysis does not imply that a choice has also been made between the unitary actor or bureaucratic/organizational (Cf. Allison 1971; and Allison and Halperin, 1972) representation of the government. Both are consistent with the adaptive framework. While the work reported here does view the national system as composed of several organizational actors the concepts developed are not restricted to a bureaucratic/organizational viewpoint. The second aspect that deserves mention is the definition of the outer environment as potentially consisting of everything that is external to the IE. This distinction is captured to a certain extent in Singer's (1961) discussion of the notion of levels of analysis. While our approach is a systems approach, it is not a systematic approach as characterized by Easton (1953), Kaplan (1957) or Parsons (1958). While part of the OE would in current international relations parlance be called the international system, this is not the same international system of which Kaplan et. al. speak. The system is the national government. What is called the international system portion of the OE is Kaplan's international system minus the nation that is under study. What is called the domestic political system in Easton's terms is also included in the OE in the same manner as Kaplan's system is included. While the physical environment of the national government consists of everything that is not part of that government, that physical environment represents only the

potential environment for the national decision system. The distinction is made here between the physical and effective OE's. That distinction rests upon what "really" impacts on the ability of the system to achieve its goals and what the system "thinks" has an impact on its ability to be goal attaining. If it were the case that the OE consisted of several independent subsystems not all of which could impact on the level of goal achievement, those subsystems independent of goal achievement would not be a part of the "real" environment. Thus in some ultimte sense, OE consists of those elements and the relations defined upon them that impact upon the level of goal attainment. From the perspective of the national decision system, the OE consists of those elements of the physical OE that are considered by the decision mechanism to impact upon goal attainment. Those portions of the physical OE that are "though" to affect goal achievement (i.e., the relevant causal linkages) are expressed in the model (M) of the system of the OE. (In other discussions of this basic framework (Thorson, 1971, 1972; Bailey and Holt, 1971) the model of the OE was termed the image of the OE. As will be seen below, a major portion of this report is concerned with perceptions of the current state of the OE. In order to avoid confusion between the image of the current state and the image of the causal operation of the OE, the term model will refer to the system's conception of the causal operation of the OE, and image will refer to the perceived "snapshot" state of the OE.) Since it is logically possible (though not too probable) that both the "real" and "perceived" environment may in fact consist of everything that is external to the IE, at a maximum the OE could consist of the total physical environment. But since it is also possible (and certainly more probable) that only

a portion of the physical environment will in fact be relevant to the goal attaining ability of the system (both from the perspective of the "real" and "perceived" OE's) the OE may not constitute the entirety of the physical environment. The final comments concern the nature of the observation and access interfaces (OI and AI). Both the OI and AI are part of the IE, i.e., they are portions of the national governmental bureaucracy. Because they perform distinct sorts of functions (emit different classes of behavior) they represent separable components. A second important observation about the OI and AI is that they need not be distinct organizational members of the national governmental bureaucracy. Consider the Wage and Price Control Board. They had the responsibility of monitoring wage and price levels (OI) and they had the power to control wage and price changes (AI). But because there were two classes of behavior that the Board could emit (observation and access) the functions of the Board can be assigned to both the AI and OI.

While the operation of general goal seeking has been described in more detail elsewhere (Anderson, 1974), the following should be sufficient to provide a context for the development of what is called the sentence writer. The national decision system has a set of goals for the configuration of the OE. Under the control of the decision mechanism the OI takes observations on the OE and sends that information to the decision mechanism. The decision mechanism then compares the image it receives of the OE with the goal state. Based upon the perceived discrepancies between the goal state of the OE and the perceived state of the OE, the decision mechanism begins to search for behaviors it could emit that would cause the OE to move closer to

the goal state. The decision mechanism uses its causal model of the OE as a means for assessing the degree to which a given behavior or set of behaviors will increase the level of goal attainment. When the decision mechanism has discovered a set of behaviors it deems acceptable, it instructs the AI to emit those behaviors. Because of the manner in which the decision system uses its causal model, both the behavior and structure of the OI and AI are affected by the content of the model. The OI will only be sensitive to those features of the environment the M has identified as important. The behavior of the AI will obviously depend to a great deal upon the content of the M (in addition to the search procedure and the acceptability criteria used by the decision mechanism) to determine the behaviors that the AI will emit and the sorts of behaviors that the AI must have the capability of emitting. The center of attention of this report, the sentence writer, intersects the communication channel between the OI and the decision mechanism. The role that it plays in the operation of the system is the generation of sentences about the current state of the OE. The total system including the sentence writer and the decision mechanism is illustrated in Figure II, along with the lines of information and control. As can be seen in Figure II, the sentence writer does not replace the OI, but rather serves to transform the outputs of the OI before they reach the decision mechanism. By separating the OI and the SW (sentence writer) it is possible to separate the information that the system receives about the state of the OE and the interpretation given to that information. While the concept of a sentence writer could have been merged into the OI, by making the SW distinct from the OI conceptual clarity is increased. With this

separation, the OI is responsible for transmitting to the SW those aspects of the OE the decision mechanism, by the use of the M, deems relevant. The SW then takes the raw information and produces an interpretation or image of the current state of the OI. This notion is in line with some people's notion of the role of the intelligence community in the decision making process of the United States. Recent news stories indicate that one position currently held by policy makers is that the CIA and DIA should report only "facts" and leave matters of interpretation to the decision makers. While the notion of reporting only the "facts" is a spurious one (de Rivera, 1968) a certain amount of conceptual clarity and analytic tractability is gained by the separation of these empirically inseparable notions. Thus the OI scans the OE and detects what will be called "discrete facts" which describe the OE. These discrete facts include such things as the current price of oil, current wheat yield, and actions, statements of action, and statements of intention on the part of other governments in the OE. The sentence writer then takes these "objective" discrete facts and produces as output "discrete sentences" (which amount to direct translations of discrete facts) and "complex sentences." Complex sentences are either composed of discrete facts of inferences based upon discrete facts and the current knowledge state of the system. While the concept of a complex sentence will be discussed more fully below, the following should give some idea of the nature of a complex sentence: Suppose that the Saudi Arabian SW receives from the OI the discrete fact: "The United States announced that it would begin an immediate airlift to resupply Israeli material lost in the war." A complex sentence based upon that dis-

crete fact might be: "The United States is ignoring our threat of an oil embargo."

This concludes the introduction of the main theme. As was discussed in the introduction, the purpose of this report is to build a framework so that the problems involved in the construction of the decision system can be posed in a well-structured manner. That portion of the decision system that will attempt to be transformed into a well-posed problem is the linkage between the OE and the IE. Thus the central question for the remainder of this report is: What characterizes the process by which information contained in the OE is transmitted and transformed into a form such that the decision mechanism can use it in its evaluation of the current state of goal attainment as a guide for determining appropriate sorts of behaviors. Before continuing with a detailed discussion of the SW, the next seciton will be concerned with the general issues of the role of images, causal models, and perception.

<u>Images, Models, and Perceptions</u>

The purpose of this section is to discuss in general terms some of the issues involved in the transmission of information from the OE to the IE. In the international relations literature attention has been paid to the concepts of perceptions and images. There have been studies of misperception (Holsti, 1965; Holsti, Brody, and North, 1965; Holsti, North, and Brody, 1968; Zinnes, 1968; Jervis, 1968); the role of belief systems (Holsti, 1962); the notion of images (Boulding, 1959, 1966; Jervis, 1970); the definition of the situation (Snyder, Bruck, and Sapin, 1962; Pruitt, 1965); and the process of selective attention (Pool and Kessler, 1965). Hendrix (1973) observes that efforts at the construction of intelligent machines (artificial

intelligence) generally make a distinction between two types of knowledge, state and process knowledge. These two notions fit very nicely into the conceptual system described above. State knowledge relates to knowledge about the world at certain instances in time (our image). Process knowledge is a body of information describing how one state may be transformed into another (our causal model). By making this distinction between process and state knowledge (or images about what is and the projection of what will be) a greater degree of conceptual clarity is gained. In the literature in the field of international relations, the distinction is seldom made. A notable exception is in de Rivera's The Psychological Dimensions of Foreign Policy (1968), where he emphasizes the distinction between the construction of reality (state knowledge) and the projection of the future (process knowledge). In fact, he devotes a chapter to each topic. There are certain conceptual advantages to be had by making this distinction (especially if one's goal is the design and construction of a mechanism that has the capability for perceiving and misperceiving). While incorrect images of the current state of the OE and faulty beliefs about how the OE responds to behaviors applied upon it both result in what is commonly known as misperceptions, there are different processes and influences involved in their production. To place this distinction more directly in an international relations frame of reference consider the surprise attack on Pearl Harbor and the Russian troop mobilization immediately prior to the outbreak of WWI. Wohlstetter's (1962) analysis of the Pearl Harbor perceptual failure on the part of the United States is clearly one of a faulty image of the current state of the OE. The signs were there that should have

indicated that something was in the making. The unintended response of Germany to the Russian mobilization during the 1914 crisis is attributable to a faulty causal model on the part of the Russians.

While the distinction between state and process knowledge is used in the artificial intelligence literature, when one examines the international relations literature cited above, one finds that very little attention has been paid to state knowledge as a separate entity. The role of a causal model often is not even mentioned. Pruitt (1965) discusses three sorts of "images" that constitute the definition of the situation: 1) predictions of the future behavior of the other nation; 2) perceptions of the basic characteristics of the other nation; and 3) conceptions of appropriate ways for dealing with the other nation. Predictions about the future behavior of other nations (the OE) is represented by the output from the causal model. Conceptions of appropriate ways for dealing with the other nation are outputs of the decision mechanism, resulting from the interaction between state knowledge, process knowledge, and the goal set. Pruitt's examples of basic characteristics are the concepts of friendly, hostile, weak, or trustworthy. Pruitt says that these characteristics are predicated of nations as a whole. They represent affective evaluations of other nations or actors. Rather than being part of either the image of the OE or the model of the OE, these evaluative assertions would be part of the current knowledge state. As will be made more explicit below, the SW only produces evaluations of the current OE. One does not directly "see" hostility, or trust. They are produced by the decision mechanism. The SW does have the capacity for generating sentences of the form: Nation X is still hostile, or

Nation Y has betrayed our trust. These sorts of sentences may change the current knowledge state by either reinforcing or contracting current evaluative assertions, but it is up to the decision mechanism to make those changes--the SW is a passive transmitter of the current state ofzthe OE. The Stanford Studies (Holsti, 1965; Holsti, et. al., 1965, 1968; and Zinnes, 1968 among others) have not made the distinction between process and state knowledge or between perceptions generated by the SW and the perceptions generated by the causal model in conjunction with the decision mechanism. While they did code references to time, they did not have a conceptual framework that allowed them to manipulate those sorts of distinctions in a manner that would be of help in the construction of the SW. Jervis (1968) ennumerates 14 hypotheses in misperception, but they either treat the notion of image in a non-systematic fashion, or they are concerned with the process of changing attitudes and beliefs (the current knowledge state). Boulding's treatment of images (Boulding, 1966, 1959) relies almost entirely upon the notions of a world view, evaluative assertions, and the problems of incompatibility among images. Holsti (1962) treats a belief system as a complete world view. While noting that included in a world view or belief system are images of what has been, is, and will be, he does not develop the structure and interrelations any further than that. He makes no distinction in the coding of the evaluative assertions of Dulles between perceptions of what the Soviet Union is currently doing, and perceptions of what the Soviet Union will do. He attempts to measure the current knowledge state of Dulles without investigating the structure of that knowledge state. Only the efforts of Pool and Kessler (1965) even begin to make the sorts of distinctions that are

being made here. Unfortunately, they go no further than to suggest several factors affecting the order in which stimuli from the OE are attended to. They do not discuss how statements describing the OE are integrated and processed so as to form a perception of the current state of the OE.

In view of the above comments, it should come as no surprise that the notion of perception of the OE as developed here is not a well-structured problem. Especially since the notion of a sentence writer appears to have received no discussion.

Giving Structure to the SW

Consider the SW for Saudi Arabia receiving the following messages from the OI:

1) The total wheat crop is X bushels
2) Y men are employed in farming
3) "Since Israel cannot continue to resist Egyptian aggression if it is not given replacement materials, we (the U.S.) will begin the immediate resupply of Israel."

The SW should be able to generate statements like the following:

1) Labor productivity is low
2) The U.S. will resupply Israel
3) The U.S. is ignoring our threat of an oil embargo
4) The U.S. is still pro-Israeli and anti-Arab
5) The U.S. is supportive of Israeli behavior
6) The total wheat crop is X bushels
7) Y men were employed in farming
8) Labor productivity is Z.

The output sentences 2,6, and 7 represent discrete sentences (direct transfers with no interpretation). The rest are examples of sentences that require the interpretation of discrete facts. As noted above, these are called complex sentences. The first question is: What are the necessary properties of a SW that could generate these eight sentences? For the three discrete sentences, the SW must be able to

parse the sentence for the basic action and place it in the short term memory of the decision system. For the last two sentences that is a fairly trivial job; in fact the SW need only recognize the first two discrete facts as being in the form of discrete sentences. For the generation of sentence 2, the SW has a somewhat more difficult task. It must be able to "know" what the central theme of the sentence is. It must have the capability to recognize that the last clause conveys the basic action. Techniques by which the SW can make that determination will be discussed below. For the generation of the complex sentence "Labor productivity is low," the SW must have the capacity for manipulating the total wheat crop and total number of farm laborers to produce a value for labor productivity (complex sentence 8). In addition, it must also have the capability for determining whether that specific value for labor productivity is high, low, or moderate. In order for the SW to produce the complex sentence: "The U.S. is ignoring our threat of an oil embargo" the sentence writer must know that a threat of an oil embargo has been made. In addition to which, it also must have a means for assessing the relationship between the threat and the discrete fact from the OI. The SW must have a characterization of the past behavior of the United States and be able to recognize that the resupply of Israel is a continuation of that behavior if it is to generate complex sentence 4. If the SW is to generate the complex sentence 5 ("The U.S. is supportive of Israeli behavior.") the SW must be able to abstract from the discrete fact support for Israeli behavior.

One property of the SW immediately follows from above--it must have access to (and there must exist in the decision system) a record

of past incoming and outgoing information. In order to generate complex sentences 3 and 4, the SW must make reference to the past threat on the part of Saudi Arabia a characterization of past U.S. action. It will be recalled from the discussion above that the SW does not make evaluative assertions. The generation of sentence 4 would seem to contradict that statement. It does not. The SW in this instance is not generating an evaluative assertion, but rather interpreting the behavior of the U.S. in light of a current evaluative assertion. The distinction is subtle, but crucial. The assertion of a general evaluation of the behavior of another nation requires the ability to observe the general pattern of behavior over an extended period of time. The SW does not have that capability. The SW receives only a single time slice, which it must interpret with respect to the current knowledge state of the system. Only the decision mechanism has the ability to observe many points in time simultaneously. Since the SW has access to the current knowledge state (both the short term and long term memories) it can make comparisons between the discrete facts and the current knowledge state.

The technique for the generation of the sentences concerned with labor productivity are relatively simple. The SW must "know" that if it "sees" values for yield and manpower it divides the crop yield by the number of farm employees to produce a value for labor productivity. A comparison then would be made against some standard for the evaluation of whether or not the level of labor productivity was high, medium, or low.

While the generation of sentences concerning labor productivity are simple and straight forward, the production of sentences 3, 4, and 5 are another matter entirely. As was discussed in Anderson (1974),

communications between various nations is linguistic. Communication takes place within a strictly defined subset of English. The grammar of the language will determine whether or not the sentence is well-formed, but it will not convey the meaning of the sentence. The SW and the decision mechanism must have the capability for the understanding of sentences in that language. In an effort to explicate what is required for the understanding of sentences in a language (and how the SW does it) attention will first be paid to some very specific and restrictive examples of how the process of understanding takes place. Once the skeleton of the process of semantic interpretation takes places, the discussion will turn to the generation of semantic interpretations of sentences in a more general frame.

The key to the semantic interpretation of sentences is the existence of a set of rules or procedures that define a set of manipulations on the basic sentence. This set of rules will be called the linguistic axioms or model. The elements of the linguistic axioms can be divided into two categories--those that are syntactically based and those that are semantically based. The syntactic axioms are responsible for the recognition phase (Cf. McKeeman et. al., 1970) of the process. The recognition phase determines whether or not a given sentence is a member of the language. Only those sentences that conform to the grammar of the language have possible semantic content. The SW must recognize a string of symbols as being a legitimate sentence in the language before it can begin the process of determining its meaning. Consider the following two sentences:

1) Colorless green dreams sleep furiously.
2) Furiously sleep ideas green colorless. (from Chomsky, 1957).

Sentences 1 and 2 could both be considered nonsensical (no semantic

content), but only sentence 1 would be considered grammatical. (Although as Wilks (1972) points out there is considerably less than total agreement on the subject.) A grammatical sentence assures that information (in the semantic sense) could be conveyed by the sentence, but it does not guarantee it. In other words, the property of being grammatical is necessary but not sufficient for the transmission of semantic information. It is also the case that the sharing of a common grammar does not insure identical semantic interpretations will be given to a sentence by two receivers. The semantic axioms are in a sense independent from the syntactic axioms. Consider the following sentence: "They are flying planes." Does "they" refer to the planes or to the individuals who are flying the planes? With respect to the English grammar this sentence is ambiguous. As will be discussed more fully below, this partial independence of syntactic and semantic axioms provides one means for the generation of misperceptions about the OE. If the meaning that was intended to be transmitted by the sender were the first sense of the above sentence and the receiver thought that "they" referred to the individuals who were flying the planes, there would be a misperception. But while there is a certain independence in the relationship between semantic and syntactic axioms, there is also a certain degree of dependency. This results from the fact that the semantic axioms are only applicable to grammatical sentences.

An appropriate question might be: What does it mean to state that semantic axioms are applicable? It turns out that the notion of applicability (or how the semantic axioms manipulate discrete facts) is central to the generation of semantic interpretations. Looking at the three discrete facts that were exhibited as examples of inputs to

the Saudi SW and the eight sentences produced as outputs, it would seem to be the case that the input sentences in some manner imply the output sentences. The total wheat crop of X bushels and the Y men employed in farming seem to imply that labor productivity is (say) high. The fact the Saudi's had issued a threat of an oil embargo and the fact that the U.S. announced that it intended to resupply Israel would seem to imply that the U.S. was ignoring the Saudi threat. That is the argument being made here. By using the notion of a set of linguistic axioms (both semantic and syntactic) that intuitive implication can be more more explicit. Specifically, the output sentences can be conceptualized as deductions about the current state of the OE with the semantic model as a set of axioms and the current knowledge state, discrete facts, and sentences (both discrete and complex) serving as the premises. Thus given the linguistic axiom: If there has been a threat of an oil embargo made to a country if that country aids Israel, and a country says that it intends to aid Israel, then that country is ignoring the threat of an oil embargo. If knowledge of the threat is in the current knowledge state of the system (the memory); if the U.S. generates a sentence (which becomes, from the perspective of the Saudi SW, a discrete fact) that the U.S. will aid Israel; then the conditions of the axioms are satisfied. The deduction can then be made that the U.S. is ignoring the Saudi threat of an oil embargo. Structurally this condition--deduction, or if-then form of the axioms--fits very nicely into the production system (see Anderson, 1974; and Newell, 1973a) conception that is planned for the construction of the decision system. A production system consists of a set of statements called productions. A production is a

statement of the form condition--action. If the condition isztrue then the action is taken by the system. In terms of the SW, if the conditions of the axiom are true, then the deduction is made. This structural similarity between production systems and the linguistic axioms has an additional desirable property besides theoretical elegance. From Klahr (1973) a production system obeys several operating rules. Those relevant to this context include:

i. The productions are considered in sequence, starting with the first.
ii. Each condition is compared with the current state of knowledge.
iii. If a condition is not satisfied, the next production rule in the order list of production rules is considered.
iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).

These four rules are easily interpreted in the linguistic axiom context. Just substitute linguistic axiom for production, and action would be replaced by deduction or semantic inference. Now consider the propositions about selective perception found in Pool and Kessler (1965):

1. People pay more attention to news that deals with them.
2. People pay less attention to facts that contradict their previous views.
3. People pay more attention to news from trusted, liked sources.
4. People pay more attention to facts that they will have to act upon or discuss because of attention by others.
5. People pay more attention to facts bearing on actions they are already involved in, i.e., action creates commitment.

By having the operation of the SW and the linguistic modelzorzaxiom set follow those four production system rules, the five propositions that Pool and Kessler identify as being aspects of the process of selective properties can be exhibited without the explicit invocation of separate structure and process. In essence, by relying upon the

notion of production systems we get something for nothing. Thus not only do production systems represent an elegant solution to the specification of the operating rules of the system, they also have embodied within them a great deal of theoretical power. Take Poll and Kessler's second proposition. By placing those linguistic axioms that would result in the generation of sentences that contradict currently held views at the bottom of the ranked list of axioms, the system can be made to behave as if it paid less attention to facts that contradict its previous views.* The propositions stating that people pay more attention to news that deals with them, to facts that they will have to act upon, and to facts bearing on actions that they are already involved in, can all be reinterpreted as stating that a decision system pays more attention to facts, news, and actions that affect the system's level of goal achievement. The placing of those linguistic axiomx relating to the goals of the decision mechanism near the top of the list of axioms will cause the predication of those three propositions to the behavior of the system. By making the conditional portions of the linguistic axioms contingent upon the amount of trust or degree of liking attributed to the source of the message, behavior consistent with the proposition that people pay more attention to news from trusted, liked sources can be exhibited. The realization of this proposition can be accomplished by placing the "trusted axioms" higher up in the list of the linguistic axioms than the "distrusted axioms." The realization of this last proposition implies that by using the production system notion to exhibit the phenomena of selec-

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* See Anderson (1974) for a discussion of how the ordering of productions will produce this result.

tive perception we are not getting something for nothing. The generality and elegance of the set of linguistic axioms is sacrificed for the production of an empirical proposition. While a formal linguist would decry this convolution of his formal system, we are not giving up anything of great consequence. Compared to the alternative of assigning a "salience score" the linguist's dismay is the IR theorist's delight.

The realization of the three propositions of selective perception that were interpreted as involving the goals of the decision system highlight an additional condition that must be placed on the form ofzthe outputs that the SW generates. The sentences produced by the SW are intended to be used by the decision mechanism as 1) a description of the current state of the OE; 2) a means for determining the level of goal achievement; and 3) inputs to the causal model to produce forecasts of future states of the OE contingent upon the application of sets of behavior by the AI. These three uses (especially uses 2 and 3) place demands upon the characteristics of the SW outputs. If the decision mechanism is to use SW outputs to determine goal achievement, the sentences of the SW must be comparable to the statements of the goals of the system. If the sentences generated by the SW are to be used as part of the inputs to the causal model of the OE, they must be in a form such that the M can digest them. Thus in the construction and specification of the linguistic axioms attention must be paid to what will be done with the output sentences. The design process must show sensitivities to the goals of the system, the sorts of inputs the causal model is capable of pocessing, and the information processing capacity and capability of the decision mechanism.

The last topic that will be discussed before a more thorough discussion of the syntactic parsing and semantic inference techniques is perhaps one of the most fundamental--that of control. Prior to this there has been some discussion of the flow of information within the system. But what Newell (1973b) has called the control structure has only informally been discussed. While the challens of communication and information do represent important aspects of the control structure, the concept of control channels changes a basically passive adaptive system into an active adaptive system. Until channels of control are specified, the system is only behaving as if it were adapting. Without the capability to change its outputs and modify its images as a result of past experience the apparent ability of the system to adapt to its environment is only that--an illusion. It must learn. The system must have the capacity to internalize past experience. The system can learn only with the existence of feedback loops and control channels. The system must have the capacity to modify its causal model of the OE. It must be able to change its perceptions of the basic characteristics of other nations. Its perceptual system must show a sensitivity to past experience. While Thorson (1972) has shown that there exists no adaptive system that can adapt to all environments, the class, number, and complexity of the environments that the system can adapt to and or adapt is a function of its ability to learn. The basic lines of control and self-modification are shown in Figure II. Of the numerous channels of control pictured in Figure II, only those dealing with the SW will be discussed here. (The others must wait the well-structuring of those system components affected.) With the ability of the system to change its current knowledge state, it becomes necessary that certain portions

of the SW be open to modification by the decision mechanism. Consider the second proposition dealing with selective perception. It states that people pay less attention to facts that contradict their previously held views. When the system's "previously held views" change, the operation of the SW must also reflect that change. It will be recalled that this proposition was realized in the SW by ranking those linguistic axioms that would generate sentences contradicting currently held views below those that generate sentences consistent with the current knowledge state. Thus the ordering of the linguistic axioms under the productions system-like control must be subject to modification. The three of the selective perception propositions interpreted as being sensitive to the goals of the decision system will also necessitate the rearranging of certain linguistic axioms as the goals of the system are modified. Since the proposition dealing with trusted or liked sources of information was realized by making axioms contingent upon the current evaluation of the source, as the state of knowledge of the system changes (which includes the current evaluative assertions) will automatically be reflected in the behavior of the SW without further modification of the SW. If the system has the ability to perform major modifications of its causal image of the OE and the introduction or elimination of goal statements, the system must have the ability to do more than simply re-order the linguistic axioms. It must have the capability to delete axioms and generate new ones. (It is doubtful that the system will have the ability to make such major modifications in light of the technical difficulties in the realization of that power. At most, we can strive for the design of a "smart" machine. The design of a truly "intelligent" machine will probably have to wait the resolu-

tion of certain fundamental issues in the field of artificial intelligence. The full specification of the process of self-modification is the topic for another report. Before we can talk about the process and techniques of self-modification, that which is to be modified must must be well structured. As of yet, the SW is not well structured enough to permit that sort of inquiry.

Semantics, Syntax, Parsing, et. al.

The purpose of this section is not to present an algorithm that will perceive discrete facts and produce semantic interpretations as outputs. While there is every reason to believe that such a presentation will evantually be made, the specification of the algorithm will be difficult--but it is not impossible. Before such a specification can be made certain issues must be resolved and certain decisions must be made. This section represents a first attempt to specify what must be overcome in order to specify a complete and effective (in the sense of computable) procedure for the mechanical generation of semantic interpretations.

The first and most obvious element that must be specific if one is to talk about the generation of semantic inferences is the thing that the semantic inferences are defined upon, language. Figure III is a working version of a language structure. It modifies a less sophisticated version presented in Anderson (1974). It should be emphasized that this structure is not a finished product. There are several respects in which it is lacking. The most obvious of which is that there is no specification of the admissible actors or of the admissable actions. It is only a list of 20 sentential forms. Furthermore in order to serve as the basis for the specification of a

SW, it must be presented in what is called a phrase structure format. As it is presently given, this is not a true grammar--only the skeleton. A phrase structure grammar has as its basis a set of phrases formed from the concatenation of other phrases and words. Consider a portion of a phrase structure grammar for English. One of the basic structures of that grammar might be a "simple sentence." A simple sentence might be defined as a "subject" followed by a "predicate." Under this structure, a sentence like: "He threw the election." would be recognized structurally as being a simple sentence, with "He" as the subject and "threw the election" as the predicate. The predicate might further be broken down as being a transitive verb and a direct object. This process of breaking down a sentence is called parsing. The first use that the grammar is put to in the semantic interpretation process is the determination of whether or not the sentence is grammatical--whether or not it is in the language. The process of recognition proceeds in a manner like the following: The sentence is scanned to determine the recognizable phrases, i.e., transitive verbs, conjunctions, adjectives, adverbs, etc. Then the sentence is rescanned to determine whether or not those phrases can be chunked to form other phrases, e.g., a transitive verb followed by a direct object is a predicate. This process of chunking continues until one of two things happens, either the sentence is reduced to one chunk or it is not. If the sentence is fully reduced it is grammatical, i.e., part of the language. If the sentence is not reducable to one chunk, the sentence is not in the language. If the goal symbol happened to be a simple sentence, then "He threw the election" could be reduced to one chunk. On the other hand, "He the election threw" would not be

reducable to a simple sentence. This is exactly the type of process used by programming language compilers when they reject statements of a program. A compiler can recognize that a = b + c is a legitimate sentence, where = a c b + is not. This process of syntactic analysis is the least problematic of the problems that are faced in the specification of the SW. In fact, given a well-formed grammar, the syntactic analysis of a language is quite straight forward. Numerous books have been written on the subject, the techniques and requirements are well-defined, and there even exist programs which will take a grammar as input and generate a program that will do the syntactic analysis. As a further illustration of how this syntactic recognition process works, consider a sentence from the language specific in Figure III: "Since Israel cannot resist Egypt if Israel is not resupplied then the U.S. will resupply Israel." From an inspection of Figure III it can ve seen that this sentence has the same structure as sentential form 13: Since _____ then _____. The quasi-phrase structure parse of this sentence is given in Figure IV. The following is a description of that parse: On scanning the sentence from left to right, the first complete sentential form that is recognizable is that of "Israel cannot resist Egypt" which is form 1. That phrase is replaced with a marker indicating a type 1 phrase. The scanning continues from left to right. The next phrase to be recognized is "Israel is not resupplied," or ACTOR is not ACTION. A marker for sentence type 6 replaces that phrase. The next phrase is that of form 3. At this point the partially parsed sentence looks like this: SINCE (1) IF (6) THEN (3). Since the end of the input string has been reached, but the reduction or chunking is not complete, the process starts

over from the left on this new string. The next recognizable phrase is that of _____ IF _____, which is form 18. The "(1) IF (6)" part of the string is replaced by (18) resulting in the following string: SINCE (18) THEN (3). The scanning is restarted from the left once more. This time the whole of the remaining string is recognized as a sentence of the type SINCE _____ THEN _____. The entire string is replaced by the marker (13), and the recognition phrase is complete, the sentence is part of the language. Notice that in the process of recognition the original sentence has been lost. This is overcome by keeping a copy of the original sentence in memory. That original sentence plus the entire phrase tree is passed on to the next stage in the process, that of synthesis. Before moving on to the topic of synthesis (which is really at the heart of the matter) a couple of comments are in order about recognition, grammars, and the particular quasi-grammar exhibited in Figure III. Upon inspection of the grammar, it can be seen that it represents a very restricted language. Not everything is expressable in that language. That is how it should be. The sort of grammar being sought is a grammar that allows one to say enough, but not too much. While it might be nice to use the entire English language as the basis for the communication in the specification of the decision system, elegant prose is not our goal. Attempts at the recognition or translation of natural language have proven to be dismal failures. No one has yet succeeded in writing down the grammar for English. Mechanical translations have produced more garbage than anything else. Natural languages cannot (as of yet) be processed mechanically. The problems in doing so appear (to some) to be insurmountable. But is has been possible to design, construct

and run machines that can handle artificial languages and/or very specific subsets of natural languages (Cf. Wilks, 1972; Minsky, 1968; and Siklossy and Simon, 1972). Thus it is impractible to use English as the basis for the language specification--but it can be done with a subset of that language. The selection of that subset is (and probably forever will be) an ill-structured problem. The subject must be able to express what must be expressed, but on the other hand, the smaller the scope of the language the easier it will be to produce a mechanical realization of it. These two trade-offs are responsible for the provisional status of the language specified in Figure III. It is not known how acceptable that language is. The ability to recognize an acceptable language requires structure. (It might seem circular that before giving structure to part A of the system, part B must bezstructured, but before part B can be structured, part A must first be structured. To a large extent that is true. A provisional structure must first be guessed at. Then through the interaction ofzthe specification of the various system parts, that provisional structure can be modified. But the closer that first guess is to the "true" structure, the quicker will be the convergence. It is by discussing the holes in the entire system before specifying the provisional structure for one of the components, can the chance that the provisional guess is close to right be increased. We will simply have to deal with ambiguity for a while.)

To help illustrate some of the problems faced in the specification of semantic inferences, consider what could be characterized as a brute force approach to the problem. One obvious way to get the semantic interpretations would be to list all possible sentences and

determine the permissible semantic inferences. That will not work for several reasons. First of all, the quasi-grammar in Figure III defines an infinite number of sentences. The recursive property of the grammar which accounts for its power implies an infinite number of sentences in the language. Secondly, as was indicated above, the semantic interpretations of a given sentence depends upon the current state of knowledge of the system. As the current knowledge state changes, the SW's semantic inferences should reflect those changes. Semantic interpretations depend upon the goals of the decision systems. As the amount of goal achievement varies, so could the semantic interpretations vary. A decision system that constantly experienced a low degree of goal achievement could view the world in a different light than a "top-dog." The phenomena of rising expectations followed by a decrease in goal achievement could cause semantic inferences to change. From this it follows that the rules of semantic interpretation must be sufficiently general so as to produce different interpretations under certain classes of differences in the state of the system. As another illustration of the issues involved, consider these four sentences in the language of Figure III: The U.S. will resupply Israel so that Israel can resist Egypt. Since Israel cannot resist Egypt if Israel is not resupplied then the U.S. will resupply Israel. The U.S. will resupply Israel because Israel cannot resist Egypt if Israel is not resupplied. The U.S. will resupply Israel. The Saudi Arabian SW should produce identical sentences given the reception of any of the four sentences. As can be seen from an inspection of the grammar, each of these four sentences is a different sentential type. One could perhaps argue that

the grammar is too sophisticated for its purposes. It may not be necessary to have four ways of expressing the same "thought." The degree of sophistication of the languages hinges upon what sorts of information are required for the decision mechanism to operate. It is possible that the decision mechanism only needs very simple statements of action to generate decisions. If it happened to be the case that the decision mechanism only needed simple statements as inputs, but was capable of generating more sophisticated statements as outputs, then a dual level of sophistication could be employed. It would be useful, if only for the purposes of "seeing what was on the decision mechanism's mind," to have sophisticated sentences generated. The SW could easily strip away all of the "unnecessary" sophistication. This would simplify the specification of the SW. No matter what the capabilities of the decision mechanism may turn out to be, it is clear that the grammar in Figure III represents a sort of upper bound on sophistication.

One possible approach to the specification of the SW is loosely analogous to the operation of the General Inquirer (Stone, et. al., 1966). The General Inquirer computer program for the content analysis of statements has as its basis a dictionary. Depending upon the relevant "cognitive dimensions," each word in the dictionary is assigned a score on those dimensions. For example if the dimensions were active-passive, strong-weak, and good-bad (Cf. Osgood, 1962) the word "bomb" would be given a score indicating very active, strong, and bad. The General Inquirer system "tags" all of the words in the text, manipulates the scores (by adding and or averaging them) and generates "perceptions." Essentially what has been done in the con-

struction of the dictionary is that the words have been assigned to equivalence classes. All those words having the same scores on the dimensions are members of the same equivalence class. The SW could also be based on a similar procedure. The SW would be provided a dictionary, but this dictionary would not contain only words. It would probably contain more phrases than words. The linguistic axioms would provide the manipulation rules for breaking down the input strings into "elemental chunks" (syntax) and for the assignment of meaning according to the equivalence classes to which the elemental chunks belong (semantics). The SW would then take the evaluations of those elemental chunks and by applying an additional set of rules, produce a general semantic evaluation. If it turns out that the decision mechanism does not need a sophisticated language to operate, this process of re-combining could be avoided. Consider the simple sentence: The U.S. will initiate an immediate airlift of replacement parts, ammunition, and planes to Israel. Replacement parts, ammunition, and planes could all belong to the equivalence class of "material support." The basic "thought" or expressed meaning of that action is: U.S. (material support) Israel. If there were linguistic axioms of the form: (country) (material support) Israel → (country) pro-Israel, anti-Arab, the semantic inference can be made. If more sophisticated statements are received as input, appropriate syntactical rules or axioms could handle the de-composition. The question is whether or not the semantics of the sentence are invariant under this process of de-composition. If more sophisticated sentences were required for input into

the decision mechanism, the question is: whether or not the semantics of the original sentence are invariant under decomposition and recomposition? The use of the techniques of a dictionary, elemental chunks, decomposition, and recomposition, seems to hold promise. By using these notions the basic requirements and properties of a SW can be identified. The question is: Can a set of linguistic axioms be specified that will meet the requirements?

Conclusion: How Well-Structured is the SW?

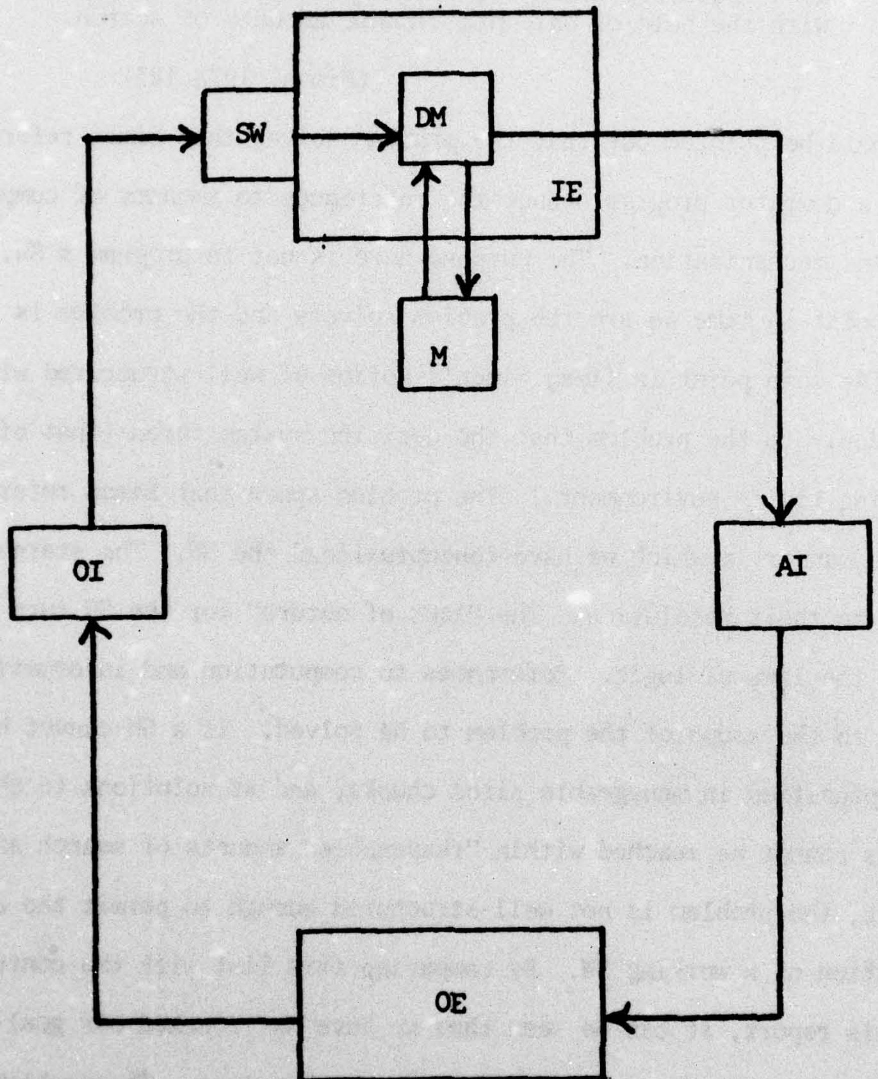
The purpose of this report has been to begin the process of specifying a well-structured problem--the sentence writer. In assessing how far we have come (and how far we have to go) Simon's criteria for a well-structured problem are of use:

> [A] problem may be regarded as well-structured to the extent that it has some or all of the following characteristics:
>
> 1) There is a definite criterion for testing any proposed solution, and a mechanizable process for applying the criterion.
>
> 2) There is at least one problem space in which can be represented the initial problem state, the goal state, and all other states that may be reached, or considered, in the course of attempting a solution of the problem.
>
> 3) Attainable state changes (legal moves) can be represented in a problem space, as translations from given states to the states directly attainable from them. But considerable moves, whether legal or not, can also be represented--that is, all transitions from one considerable state to another.
>
> 4) Any knowledge that the problem solver can acquire about the problem can be represented in one or more problem spaces.
>
> 5) If the actual problem involves acting upon the external world, then the definition of state changes and of the effects upon the state of applying any operator reflect with complete accuracy in one or more problem spaces the laws (laws of nature) that govern the external world.

> 6) All of these conditions hold in the strong sense that the basic processes postulated require only practicable amounts of computation, and the information postulated is effectively available to the process--i.e., available with the help of only practicable amounts of search.
>
> (Simon, 1973:183)

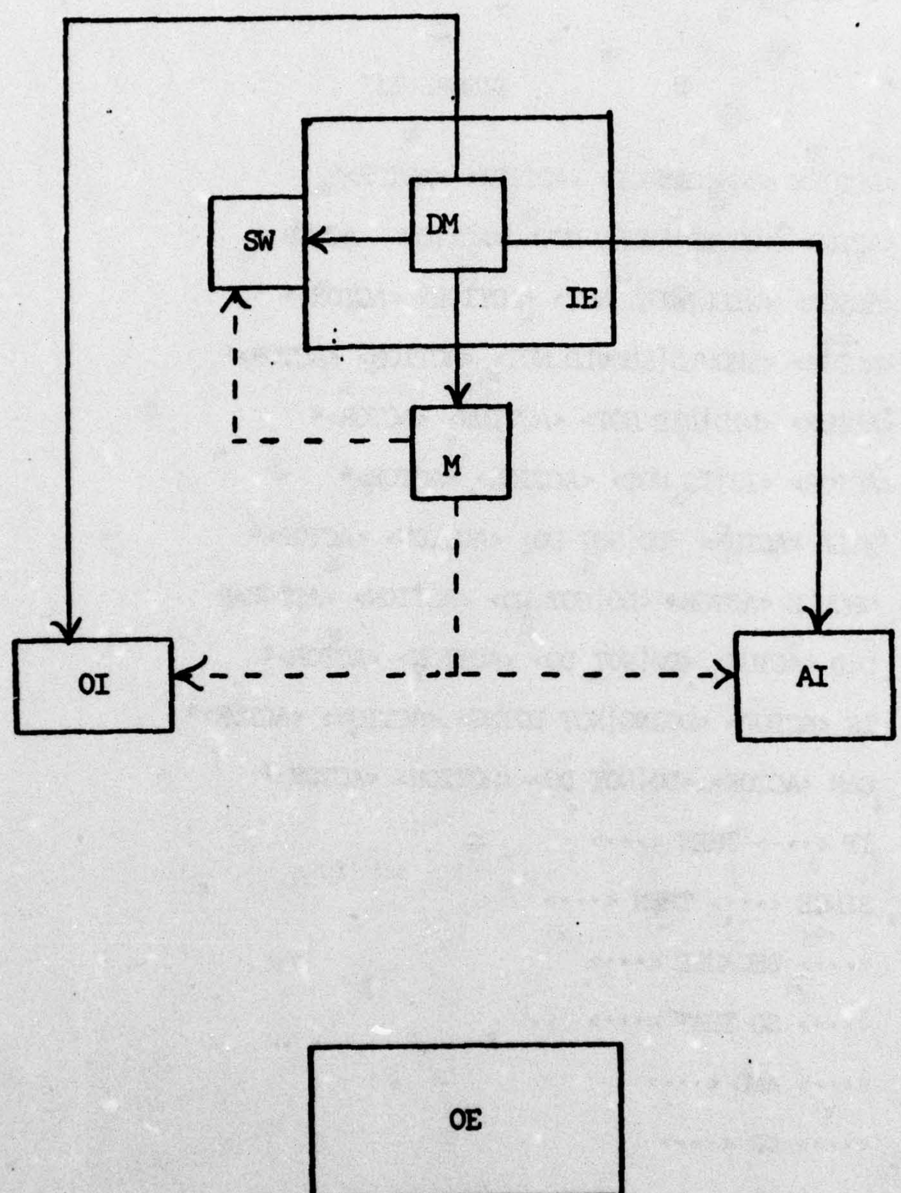
It should be pointed out that the problem solver that Simon refers to is a computer program, hence the references to amounts of computation and mechanization. The purpose here is not to program a SW. At this point in time we are the problem solvers and the problem is the SW. (At some point in time, Simon's notion of well-structured will also apply to the problem that the decision system faces--that of adapting to its environment.) The problem space that Simon refers to is the manner in which we have conceptualized the SW. The states refer to their resolution. The "laws of nature" for the SW turn out to be the laws of logic. References to computation and information refer to the scope of the problem to be solved. If a SW cannot be conceptualized in manageable sized chunks, and if solutions to the issues cannot be reached within "reasonable" amounts of search and effort, the problem is not well-structured enough to permit the construction of a working SW. By comparing this list with the content of this report, it can be seen that we have not reached our goal--structure still eludes us. But all is not hopeless. The problem space is much more clearly specified, the basic issues and requirements have for the most part been identified. It does not appear that the SW will require "excessive amounts of computation" to conceptualize. We have what amounts to an initial problem state. The goal is known. It must only be realized.

FIGURE I



IE: Inner Environment
OE: Outer Environment
AI: Access Interface
OI: Observation Interface
SW: Sentence Writer
DM: Decision Mechanism
M: Model of the OE

FIGURE II



IE: Inner Environment
OE: Outer Environment
AI: Access Interface
OI: Observation Interface
SW: Sentence Writer

DM: Decision Mechanism
M: Model of the OE

———— : Direct Control
------: Indirect Controling Influence

FIGURE III

1: <ACTOR> <CAN|CANNOT> <ACTION> <ACTOR>*

2: <ACTOR> <COULD|COULD NOT> <ACTION> <ACTOR>*

3: <ACTOR> <WILL|WILL NOT> <ACTION> <ACTOR>*

4: <ACTOR> <SHOULD|SHOULD NOT> <ACTION> <ACTOR>*

5: <ACTOR> <DID|DID NOT> <ACTION> <ACTOR>*

6: <ACTOR> <IS|IS NOT> <ACTION> <ACTOR>*

7: WILL <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

8: SHOULD <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

9: DID <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

10: IS <ACTOR> <DOING|NOT DOING> <ACTION> <ACTOR>*

11: CAN <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

12: IF <•••> THEN <•••>

13: SINCE <•••> THEN <•••>

14: <•••> BECAUSE <•••>

15: <•••> SO THAT <•••>

16: <•••> AND <•••>

17: <•••> OR <•••>

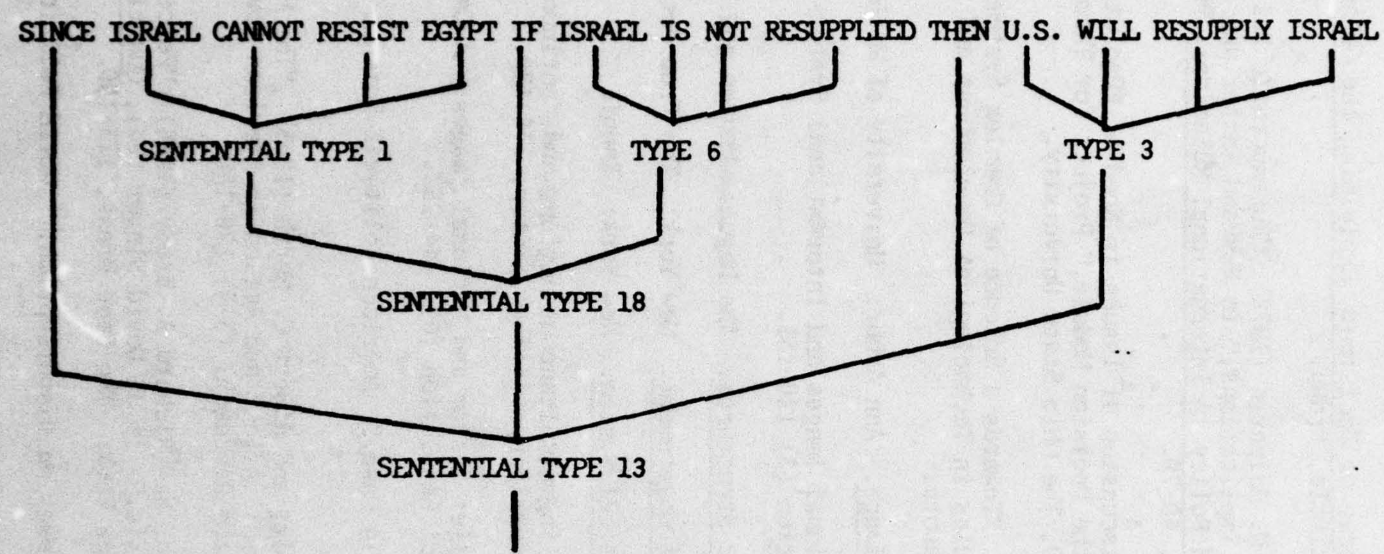
18: <•••> IF <•••>

19: <•••> AND NOT <•••>

20: <•••> OR NOT <•••>

* Optional; the actor (target) may be omitted.
| means that one of the two choices should be selected.
••• means that any one of the 20 sentential forms may be selected.

FIGURE IV


SINCE ISRAEL CANNOT RESIST EGYPT IF ISRAEL IS NOT RESUPPLIED THEN U.S. WILL RESUPPLY ISRAEL
SENTENTIAL TYPE 1
TYPE 6
TYPE 3
SENTENTIAL TYPE 18
SENTENTIAL TYPE 13

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Modeling Control Structures for
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MODELING CONTROL STRUCTURES FOR COMPLEX SOCIAL SYSTEMS

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Abstract

Basic systems concepts are reviewed and used to define artificial systems. The artificial system structure is given both a control theoretic and a "political science" interpretation. Under the political science interpretation, the inner environment becomes the government and the outer environment the system external to the government. The concept of "complexity" is discussed from a systems theoretic perspective and implications are drawn for the modeling of governments as control structures. Several principles - hierarchical organization, multiplicity of goals, and potential redundancy of control - are offered to aid in restricting the class of control structures possibly admissible as models of governments. Production systems are proposed as a possible approach to the development of control structures which satisfy these principles. The notion of a production system is illustrated with a simple example.

A number of scholars have employed "systems concepts" in investigating phenomena from the domain of international relations (e.g., see Rosenau, 1970; McGowan, 1970; Forrester, 1971; Phillips, 1974). However, the number of systems oriented researchers who have explicitly considered what might be called the "control structures" of the social systems they study is relatively small. For example, Forrester's well known "World Model" contains no explicit decision making mechanisms and unless run interactively, his simulation is mechanistic.

Yet even casual observers of the international scene are often struck with the seemingly adaptive nature of national foreign policy behaviors. Alliances often seem to shift in apparent response to changing "realities" such as a perceived scarcity of crude oil. Yet, as with most all adaptive mechanisms, the range of adaptation has limits. Some policies (perhaps the U.S. policy toward China would serve as an example) change very slowly and the reasons seem more related to the internal politics of government than to the external environment the government is attempting to deal with.

If the sorts of behaviors described above are taken to be roughly descriptive of international politics, then clearly any theory of, say, foreign policy behavior must be capable of accounting for these kinds of observations. Such an accounting requires a careful consideration of the control structures of the systems being studied. The purposes of this paper will be to explicate what is meant by control structure in this context and to suggest some organizing concepts of possible use in modeling these structures.

§ 1 Introduction

In order to put the following discussion into a unified perspective, it will be helpful to provide an overview of some basic systems concepts. Since these concepts are treated in detail elsewhere, what follows will simply be a review of basic definitions.

Following Mesarovic (1967) systems will be viewed abstractly as set-theoretic structures. More specifically:

> "Let a family of objects be given $V=\{V_i|i\epsilon I\}$ where I is the index set for the family V. A system S is simply a relation defined on V, i.e.
>
> $$S\subset x\{V_i|i\epsilon I\}$$
>
> where x indicates cartesian product.
>
> On the basis of this definition, general systems theory becomes simply a general theory of relations. Following a formalization approach, one starts from such a general notion of a system and then proceeds to assume more structure for the object $V_1, \ldots V_n$ and investigates the properties induced by the relation S (p. 223)."

In this context, the family V is simply a collection of sets of objects V. The set I is used to index the sets in V. The use of object here may be thought of as a generalization of the notion of a variable. The members of a particular object set then become possible values or "appearances" for the object. As an example, a student of international politics coding the affective aspect of national foreign policy behaviors as being either friendly or hostile could be viewed as measuring the object named affect. The elements or appearances of the object would be (friendly,

hostile). Most systems of interest will have more than one object and an appearance of a system can be given by listing the appearance of each object in the system. In the case of dynamic systems (those directly parameterized by time) a concern is often with relating system appearances at one time to system appearances at future or previous times.

From this general definition of system it is possible (Mesarovic, Macko, and Takahara, 1970) to move to a familiar "black box" view of a system where the object family V is broken into an input set U, and output set Y and a state set Z. The system can then be rewritten as:

$$S:\ Z \times U \to Y \qquad (1)$$

That is, the output of the system is a function (in the mathematical sense) of the input and the present state of the system. A minimal description of a system in this sense requires identifying the set of input objects (U), the set of state objects (Z) and the set of output (Y) objects together with a state transition function ($Z \times U \to Z$) and the output function ($Z \times U \to Y$). Several observations about this approach are relevant. First, the sets U and Z need not be disjoint. Second, the specification of Z and the state transition function is generally not unique. The state objects in Z are simply selected in such a way as to make the system "functional" in the sense described in (1). Third, no disturbance term has yet explicitly entered into the framework.

In theorizing about international relations, it has been suggested that it is possible to put more structure into the general "black box" view of systems by viewing foreign policy behavior from the perspective of "adaptive systems" (Rosenau, 1970, McGowan, 1970, Thorson, 1974). Such systems belong to the general class labelled by Simon as "artificial systems" and are characterized by being directed toward human goals. According to Simon (1969):

> "1. Artificial things are synthesized (though not always or usually with full forethought) by man.
>
> 2. Artificial things may imitate appearances in natural things while lacking, in one or many respects, the reality of the latter.
>
> 3. Artificial things may be characterized in terms of function, goals, adaptation.
>
> 4. Artificial things are often discussed, particularly when they are being designed, in terms of imperatives as well as descriptives [pp. 5-6].

An artificial system has a number of components or subsystems. There is an inner environment (I.E.) which is "attempting" to achieve goals in an outer or task environment (O.E.). The I.E. receives information about the O.E. through an observation interface and send policies or behaviors into the O.E. through an access interface. Finally, in order to evaluate alternative policies (without actually implementing them) the I.E. must have a representation or "image" of the outer environment. The structure common to artificial systems is shown in figure 1 .

For the purposes of this paper, the I.E. will be interpreted as being a national government and the O.E. as that which is external to the government (including objects from both "domestic" and "international" domains). The observation interface includes those aspects of the I.E. which are charged with monitoring the appearances of the O.E. while the access interface includes those aspects of the government responsible for getting policies into the O.E.. The "image" includes the governments long and short term images (to be explicated below) as well as various planning and forecasting components.

Prior to providing a simple illustration of these components several comments on this approach are in order. First this approach requires no "in principle" position on a unitary rational actor approach versus a bureaucratic/organizational approach (Allison, 1971; Halperin, 1974). While the course taken here is compatible with the organizational perspective, some of the arms race work (e.g., Brito, 1972) could be restructured into the artificial systems framework and, as such, would represent a unitary rational actor approach. Second, the use of the observation interface allows a clear distinction between the O.E. as it "really" is and the O.E. as filtered by the observation interface. Finally, care should be taken not to reify the objects in the artificial system. Objects believed to be in the world may be represented as being objects in more than one component. For example, the U.S. Wage and Price Control Board had the responsibility of monitoring wage and price levels (observation interface) as well as the responsibility to effect wage and price changes (access interface). Thus the Board can be assigned to both the access and observation interface.

An understanding of how the artificial systems components inter-relate can be enhanced by going through a simple example. Let the inner environment (I.E.) represent a country's economic policy bureaucracy and the outer environment (O.E.) represent the country's economy. Assume further that the bureaucracy's objective is to keep the economic system in a certain specified set of acceptable states. The state of the economy is then represented by the vector $\underline{x}$ and might include such things as each citizen's income, all sales transactions, and other such objects.

The officials must have some way of observing $\underline{x}$ so that they can determine whether the economy is in an acceptable state. However, they can not observe each and every sales transaction, etc., directly. In fact, even if all this information could be obtained, it would probably exceed their information processing capability. Therefore they must filter all of the minute economic information into

something manageable. This is the task of the observation interface and would include various agencies to collect and aggregate economic data. Since, in this example, $\underline{x}$ would contain far too much information, the observation interface might incorporate some sort of indicator system. Thus instead of having $\underline{x}$ as an output, the I.E. receives $\underline{y}$. The vector $\underline{y}$ might include such indicators as GNP and unemployment rates. In some cases $\underline{y}$ and $\underline{x}$ will be equivalent. Most often, however, this will not be the case and the notation reflects this possible distinction.

Upon receiving $\underline{y}$, the I.E. must evaluate it to determine what sort of policy is indicated. The results of this evaluation will depend in part upon I.E.'s image of the O.E. The image might for example, consist of a Brookings forecasting model of the economy. Generally, this image will, at least in part, contain the elements of $\underline{y}$. In this way $\underline{y}$ can be used to set the "state" of the image and various policy alternatives ($\underline{\hat{u}}$) can be put into the image to access their differential impacts ($\underline{\hat{y}}$).

The elements of the $\underline{u}$ vector, to have any impact, must have some way of getting into the O.E.; that is, the I.E. must have some access interface which is capable of implementing $\underline{u}$ in the O.E. Fiscal and monetary policy might serve as accesses.

This very crude economic example hopefully makes more clear the basic components of an artificial system. In addition, it should serve to illustrate the high degree of inter-relation between the components. This example was <u>not</u> intended to suggest that the components of an artificial system will have simple "real" world interpretations. The distinction between the components is analytic and it may be that the vocabulary generally used in theorizing about governments is incapable of reflecting these distinctions. In using artificial systems concepts to construct empirically grounded theory, it may be necessary to develop some new terminology.

This overview, while superficial should provide clues to the systems framework which will be employed in this paper. Specifically, systems are viewed as set theoretic structures. Explicit acceptance of such a view makes it difficult for the theorist to fall into the trap of reifying systems. A system is something the theorist posits to stand in some relation to objects he believes to comprise (parts of) the world.

Further, the abstract notion of a system as a relation on the cartesian product of objects (i.e., sets of appearances), forces the theorist to specify the objects about which he is theorizing. All too often, especially in theories expressed in natural languages such as English, the tendency is to assume that "everyone knows" what is being theorized about. Since "everyone knows", there is no need to specify explicitly what objects make up that world. Yet, it can be argued that theories are not about the world but about "representations" of the world (or indeed, there may be many worlds), and it is useful to make public that representation by specifying it as unambiguously as possible.

This specification can begin by writing down the objects (and their possible appearances) which populate the representation. It is completed when, in addition, the theoretically allowable conjunctions of appearances are specified. The fact that the set of logically possible conjunctions of appearances is greater than the set of theoretically allowable conjunctions is what gives structure to the world and allows scientific theorizing to be at all successful. Writing down the world being theorized about is equivalent (under the terminology of this paper) to specifying the system the theory is about.

§ 2 Complexity

The artificial systems framework discussed in the previous section is structurally very similar to a systems control problem. In control theoretic vocabulary the I.E. is the "control mechanism" and the O.E. is the "process" or "plant" being controlled. Arbib (1972) described a control problem as: "Given reasonably accurate descriptions of a system and some performance required of it, to find inputs which, when applied to the system, will elicit (a reasonable approximation to) the desired performance (p. 80)." Viewing a government as a control mechanism (which must be done if it is asserted to be "adaptive") does not require that it be considered an <u>optimal</u> control mechanism (i.e., that it produces "best" policies). Such a view does, however, allow the use of many control theoretic concepts in the development of theory.

Given a control perspective, there are several general sorts of questions the analyst might ask. First, for particular nations, what do the goals, inner and outer environments look like? Second, given an inner and outer environment, (that is holding the structure of the inner and outer environment fixed) how can certain goals be "best" achieved? And third, given some set of objectives, what sorts of inner and/or outer environments can "best" achieve them? These can be termed questions of description, policy, and design respectively. Elsewhere (Thorson, 1975) it is argued that these questions can be ordered in the sense that an answer to policy questions will generally require having fairly good answers to descriptive questions and that solutions to problems of political design will require prior work in the policy and descriptive areas. However, the focus of this paper will be essentially upon description. Description is being used in a very general fashion to refer to a standard concern in constructing scientific theory - accounting for observations, identifying interrelationships among them, and predicting new observations.

At its most abstract level, the descriptive problem is made difficult by the apparent complexity of the international system. Von Neumann (1966), for example, argued, "It is characteristic of objects of low complexity that it is easier to talk about the object than produce it and easier to predict its properties than to build it. But in complicated

parts of formal logic it is always one order of magnitude harder to tell what an object can do than to produce the object. The domain of validity of the question is of a higher type than the question itself." While the precise meaning of this passage may be unclear, Von Neumann seems to be suggesting that as systems get beyond some threshold level of complexity, modes of understanding them change. Shaw (1970) uses Von Neumann's statement to conclude that "any science, like psychology, which desires formal models of highly complex systems, like organisms, will have to consider Von Neumann's conjecture a threat to the fulfillment of its explanatory goals." Indeed, the claim is often heard that the relatively primitive state of the social sciences can be attributed to the complexity of the phenomena.

Given the prime-facia plausibility of the "argument from complexity," it will be useful to explicate somewhat more completely what might be understood by complexity in a systems context. Forrester (1969) defines complex systems as systems with "a high-order, multiple-loop, nonlinear feedback structure," and he argues that such systems behave very differently from the simple systems often encountered. Forrester's position is a special case of the more general view (Levins, 1970) that complex systems are systems with many objects and few constraints in the relations between the objects. As a simple example of the impact of the number of objects (i.e., variables), consider a social system with N objects. Object j in this system takes on the appearance N with probability $^1/N$ and the appearance 0 with probability $1 - {}^1/N$. As N gets very large, the expected appearance of object j goes to 1, yet the probability of ever observing j in an appearance other than 0 goes to 0. It is unlikely that even the most sophisticated empirical work would uncover object j, yet from say a policy standpoint the presence of j in the system, even at 0 value, may be of extreme importance in designing policies.

From examples such as these it is tempting to conclude that complexity is an "intrinsic" characteristic of a system. However, for a variety of reasons it appears that no adequate characterization of the complexity of a system can be given independent of the class of systems operating (or, in the sense employed here, controlling) with that system. The reason for this is that the structure of a "controlling" system can be so designed as to remove some of the "intuitive intrinsic complexity" from its environment. For example, many living species may well be facing a less complex environment now than they did thousands of years ago. Through evolution many of the common relational structures have been "preprogrammed" into the human brain. That is, the brain has developed in such a way as to operate extremely effectively in an environment of three dimensions, fast response time (the time it takes for the environment to respond to external stimuli), and few relevant variables. This preprogramming through evolution or design may well be a key to any system's behaving adaptively in a seemingly complex environment.

Baby salamanders, for example, live completely on land for a time after they are born before entering the water in search of new forms of food. Is their ability to swim learned in some fashion; perhaps by imitating other salamanders or by trial and error? Coghill (1929) anesthetized a salamander at birth and kept it in this condition for the length of time salamanders had been observed to remain on land before beginning to swim. After this time had elapsed, the salamander was dropped into water. Even though no learning could have taken place, the salamander was able to swim effectively. The reason for the delay between the time of birth and the onset of the ability to swim was that, as a part of the maturation process, a certain neural connection had to be made in the salamander's spinal cord. The ability to swim is preprogrammed into the developmental process of the salamander. The effect of dropping a one week old salamander into a pool of water would be very different from that of dropping a five month old salamander into the same pool. Does the complexity of the pool of water change if one animal is able to deal effectively with it while another is not? A more rigorous example drawn from automata theory might make this point more clearly. The problem is to design a Turing machine which can determine whether a string of symbols reads the same backwards as forwards (as in ABLE WAS I ERE I SAW ELBA). Arbib (1969) proves that, for a Turing machine with one reading head the time necessary to decide the problem increases with the square of the length of the symbol sequence. For a Turing machine with two reading heads, however, the time increases only as a linear function of the sequence length. If the complexity of the problem is indexed by the time required to solve it, it is clear that the internal structure of the "solving machine" must be specified rather carefully.

These examples lead to a conclusion similar to that of Nurmi (1974), "Complexity can be viewed as an ontological property of the relationship between the actor and the environment (p. 84)." As long as the focus of study is systems with control structures, complexity must be viewed in a contingent fashion. The next section will suggest implications of this contingent view for theorizing about control structures.

§ 3 Control Structures

Mention has been made of the similarity between an adaptive systems approach and a control theoretic perspective. If governments are to be convincingly modelled as control structures, it is important that the models be capable of exhibiting a similar range of behaviors as do the governments being modelled. For example, most governments are organized hierarchically, have multiple (sometimes conflicting) goals and exhibit "redundancy of potential control." While there are numerous other properties which might be predicted to governments, the above three are enough to greatly limit the class of admissable control structures. Since the first two of these have been treated in some detail elsewhere (Anderson, 1974; Phillips, 1974;

Thorson, 1974), only the "redundance" notion will be discussed here.

According to Arbib (1972, p. 17) the principle of redundancy of potential control "states, essentially, that command should pass to the region with the most important information." As an illustration Arbib (who attributes the example to Warren McCulloch) cites "a World War I naval fleet where the behavior of the whole fleet is controlled (at least temporarily) by the signals from whichever ship first sights the enemy, the point being that this ship need not be the flagship, in which command normally resides (p. 17)." The critical point here is that potential control need not reside in only one portion of a government. Indeed the way in which various governments resolve the redundancy is critical to understanding and explaining its behavior.

If it is accepted that governments are characterized by redundancy of potential control then very careful attention must be paid to how research questions about governmental behaviors are posed. In another context Newell (1973a) was critical of a view of science which holds that:

> Science advances by playing twenty questions with nature. The proper tactic is to frame a general question, hopefully binary, that can be attacked experimentally. Having settled that bits-worth, one can proceed to the next. The policy appears optimal . . . Unfortunately the questions never seem to be really answered, the strategy does not seem to work (p. 290).

As an alternative, Newell proposes the development of "complete processing models." Such complete models of necessity include a specification of the entire control structure. Such a specification would seem especially appropriate in the face of control redundancy since studies focusing on only a portion of the control structure will generally fail to face the critical question of under what circumstances control passes from one location to another.

One way to begin to develop answers to these questions is to put more structure into the "image" component of the artificial system. In order for a government to respond adaptively to O.E. changes it is essential for there to be some sort of image of the O.E. This use of image is not meant to suggest the existence of a "picture" of the O.E. somewhere in the government archives. Rather, the concept is used abstractly to refer to that portion of the I.E. which "organizes" past O.E. behaviors and thereby uses new information to trigger responses. In this sense it is useful to distinguish two sorts of images. The first is a long term image (LTI) and includes representations of relatively invariant properties of the O.E. Within many bureaucracies rather formal standard operating procedures act as a LTI. More ambient or current information about the O.E. is stored in what might be called the short-term image (STI). The contents of the STI is used in conjunction with the LTI to determine precedence of control within the I.E.

This distinction between the STI and the LTI leads very naturally to a particular way of modeling the control structure of the "complex" artificial system - that of production systems. A production system is a means of explicitly modelling redundancy of potential control. "It consists of a set of productions, each production consisting of a condition and an action (Newell, 1973b, p. 463)." Productions are rules stated in the form of a condition and an action: C→A. In our terms, the "condition" refers to the contents of the STI and the actions may involve policy changes (u) intended to lead to goal satisfaction or, more frequently to changes (transformations) on the STI. These changes involve modification (including deletions) of content of STI as well as addition of new content (which may appear externally as a switch in control. A more complete description of the rules governing production systems is provided by Klahr (1973):

> i. The productions are considered in sequence, starting with the first.
> ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in (STI). If all of the elements in a condition can be matched with elements (in any order) in (STI), then the condition is satisfied.
> iii. If a condition is not satisfied, the next production rule in the ordered list of production rules is considered.
> iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).
> v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.
> vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.
> vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost. (p. 528-529).

A substantive example of a rather simple (and very stylized) production system is provided in Figure 2.*

The production system in Figure 2 is an attempt to describe the behavior of the Libyan Revolutionary Command Council. Recently Kaddafi was asked to step down from his political-diplomatic position

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* Paul Anderson and Michael Hainline assisted in the development of this example. A more complete description may be found in Anderson (1974).

but retain his position as Commander-in-Chief of the Libyan armed forces. The illustrative production system is an attempt to specify those conditions under which the Council will request that Kaddafi step down. This production system was built upon the assumption that the reasons that Kaddafi might be asked to step down reflect the perception on the part of the members of the Council that things are not going well for Libya. Some of the indicators picked up through the observation interface that the Council might consider are: fiscal irresponsibility, food shortages and excessive religious orthodoxy. It was also assumed that the Council was more willing to ignore some of the bad points (marks in the production system) if there were favorable aspects of the situation to off-set the marks. For example, if Sadat looses face, there is an increase in skilled labor, or if there is a food surplus (relatively), the council will overlook some of the bad points about Kaddafi's management. If it is the case that even with the good points, Kaddafi has managed to accumulate four marks, the Council will request his resignation. Initially the STI of the Council is filled with NIL or blank symbols. Since none of the first 15 productions will be satisfied, the sixteenth production, which contains no condition will be executed. The action READ means that the Council looks at the environment and takes a reading of the current state. As long as the symbol read from the environment does not invoke a production, the system will continue reading until one is found. Suppose the first "recognizable" symbol is a food shortage. After it is placed in the STI by the READ operation, production 5 will be executed. This results in FOOD SHORTAGE being marked as OLD. The OLD ** operator is a replacement that modifies the contents of the STI. After the matched symbols have been moved to the top of STI, the first symbol in STI is replaced by (OLD **), where ** is replaced by the first symbol. This prevents the system from counting FOOD SHORTAGE twice, since FOOD SHORTAGE and (OLD FOOD SHORTAGE) are not the same. The production also results in a MARK being placed in STI. If at any time, Kaddafi has supported four radical foreign causes with no noticeable achievement, production 7 is executed, which results in all four supports of radical foreign causes being marked as old, and the addition of a MARK to the STI. If it happens that there is an increase in skilled labor when there is also a MARK in STI, both the skilled labor increase and the MARK are masked. In essense, one of the strikes is erased -- although it still takes up a position in the STI. If at any time, Kaddafi has managed to accumulate four MARKS, the symbol REQUEST will be placed in STI. This results in the Revolutionary Command Council asking Kaddafi for his resignation.

Notice that all of the productions that erase 'marks' from the STI are at the end of the system. This means that a mark can only be erased if there are no 'bad things' in the STI. If the set of productions that erased marks were to be moved to the top of the system, the chance for an erasure would be greater (and the chance for removal less). If production 3 were placed at the end, the only time that Kaddafi would be asked to step down would be when neither anything good nor bad was happening. If it were inserted after production 11, the only time that he would be asked to resign is when he had accumulated four strikes, and at the present time all was going well, i.e., the short term memory was filled either with junk or positive symbols. Depending upon the sorts of things that the Council could be expected to receive from the environment, by rearranging the individual productions, the chance that Kaddafi would be requested to step down could be varied. Thus it is not enough to say that fiscal irresponsibility and food shortages count against Kaddafi in the eyes of the Council. One must be more specific about exactly what the conditions are that will cause the Council to request his removal.

Research is presently underway to develop more sophisticated sets of production systems for particular governments. The access interface is being modelled as receiving strings of symbols (<u>x</u>) from the O.E. and operating on these symbols. These operations then produce (<u>y</u>) for the STI of the various production systems comprising the I.E. Redundancy of control will be determined by the production systems in conjunction with the content of STI. Such a procedure allows multiple goals (conflicting or not) to be "considered." The goals are imbedded into the structure of the production systems and resolution of the redundancy question in effect "resolves" the problem of conflicting goals.

§ 4 Conclusion

While the arguments presented in this paper do not really settle any substantive issues, they do suggest certain strategies for doing research - both theoretical and empirical - on the behavior of nations. First, explicit attention must be paid to the control structure of the government. Second, if the principle of "potential redundancy of control" is accepted then a "complete processing model" approach is indicated. That is, theories must be able to account for how redundancy is resolved. Research focusing only upon "sub-control" modules will not provide answers to this question. Third, such complete processing models may be too "complex" to provide <u>useful</u> analytic solutions. As Levins (1970) points out:

> Suppose we did know the interrelations among all parts of a system and could describe the rate of change of each variable as a function of the others. Then we would have a very large set of simultaneous non-linear equations in a vast number of variables, and depending on so many parameters, the estimation of each of which may take a lifetime. . . . These equations will usually be insolvable. They would likely be too numerous to compute. If we could solve the equations the answer would be a complicated expression in the parameters that would have no meaning for us (p. 75).

Thus it may be necessary to rely upon computer simulations to provide a basis for experiments on control structures. Production systems are a possible mode of representing these control structures.

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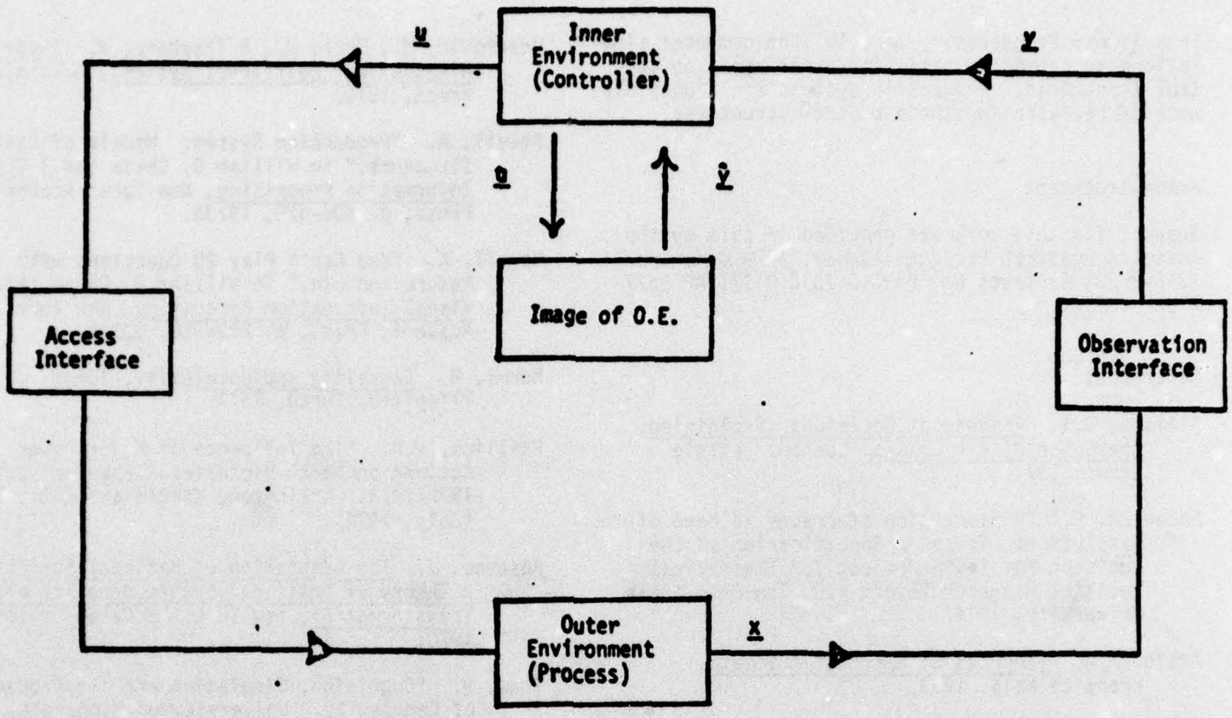

Figure 1 Artificial System Structure

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PS:  LRCC74
STI: (NIL  NIL  NIL  NIL  NIL  NIL  NIL  NIL)

1:  (STOP) → END
2:  (REQUEST) → (OUTPUT  "RESIGNATION", STOP)
3:  (MARK,MARK,MARK,MARK) → (OLD(**),REQUEST)
4:  (FOOD SHORTAGE,FISCAL IRRESPONSIBILITY,NEGATIVE FOREIGN
         COMMENT BY AN ALLY) → (OLD(**).REQUEST)
5:  (FOOD SHORTAGE) → (OLD(**),MARK)
6:  (SUPPORT OF RADICAL FOREIGN CAUSES,NO ACHIEVEMENT) → (OLD(**),MARK)
7:  (SUPPORT OF RADICAL FOREIGN CAUSES,SFRC,SFRC,SFRC) → (OLD(**),
         FISCAL IRRESPONSIBILITY)
8:  (FISCAL IRRESPONSIBILITY) → (OLD(**),MARK)
9:  (NEGATIVE FOREIGN COMMENT BY AN ALLY → (OLD(**),MARK)
10: (BAN CIGARETTES or BAN ALCHOHOL or BAN LUXURIES) →
         (OLD(**),ORTHODOXY)
11: (ORTHODOXY,ORTHODOXY,ORTHODOXY,ORTHODOXY) → (OLD(**),MARK)
12: (FOOD SURPLUS,MARK) → (OLD(**))
13: (SUPPORT RADICAL FOREIGN CAUSES,ACHIEVEMENT,MARK) → (OLD(**))
14: (INCREASE IN SKILLED LABOR,MARK) → (OLD(**))
15: (SADAT HAS TROUBLES,MARK) → (OLD(**))
16:  → READ

* SFRC = SUPPORT OF RADICAL FOREIGN CAUSES
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Figure 2 A Simplified Production System

The Role of Complete Processing Models in
Theories of Inter-Nation Behavior*

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ABSTRACT

The Role of Complete Processing Models in
Theories of Inter-Nation Behavior

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This paper falls into two portions. The nature of the scientific enterprise is considered in the first portion. The question is asked: Why does the field of international relations fail to exhibit the cumulative quality that characterizes a science? The reason for the lack of cumulativity is argued to be the tendency to formulate research questions too narrowly. "Complete processing models" are offered as an alternative to the current style of theorizing. The role of computer simulations in this alternative theoretical style are briefly discussed. An illustration of this alternative approach comprises the second portion of the paper. After discussing the implications of modeling the national government as a goal seeking system, specific techniques and approaches to the simulation of a general goal seeking model are illustrated and discussed.

The Role of Complete Processing Models:

Diagnosis and Prognosis

Upon a reading of recent prefaces and other introductory remarks by scholars in the field of international relations, one is struck by a growing dissatisfaction in the field (Cf. among others, Jones and Singer, 1972; Wilkenfeld, 1973; McGowan and Shapiro, 1973; Alker and Bock, 1972; and Deutsch, 1973). What disturbs them is the fact that the cumulative quality of the scientific enterprise that we have all awaited with high expectations has failed to develop. The recurrent theme is: Why haven't we been able to put it all together? There are no bridges between our "islands of theories" (Cf. Guetzkow, 1950). For some the answer lies in the further identification of potent variables (Wilkenfeld, 1973). For others, it is in the communication of basic findings and propositions (Jones and Singer, 1972; McGowan and Shapiro; Alker and Bock, 1972). If we look around at our sister disciplines in the social sciences we find that our problem is not unique. We are not alone in our feelings of distress. In a recent paper, Allen Newell (1973a) wrestled with the same problem. He asked his colleagues in the field of psychology:

> Suppose you had all those additional papers [that you will write until the time of your retirement], just like those of today (except being on new aspects of the problem), where will psychology then be? Will we have achieved a science of man adequate in power and commensurate with his complexity? And if so, how will this have happened via these papers that I have just granted you? Or will we be asking for yet another quota of papers in the next dollop of time? (p. 284).

In an attempt to come to grips with the somewhat disturbing question

he asked, Newell posed another question: Can you play 20 questions with nature and win? Beyond the field of psychology, it seems to me that the answer to this question has relevance for efforts at the explanation of the behavior of human systems from a small group to a nation and beyond. Newell's 20 questions game is a characterization of a strategy for doing science. This strategy is based upon the view that

> [s]cience advances by playing twenty questions with nature. The proper tactic is to frame a general question, hopefully binary that can be attacked experimentally. Having settled that bits-worth, one can proceed to the next. The policy appears optimal--one never risks much, there is feedback from nature at every step, and progress is inevitable. Unfortunately, the questions never seem to really be answered, the strategy does not seem to work. (Newell, 1973a:290)

Instead of just accepting Newell's assessment of psychology as characterizing the field of international relations, it would seem prudent to see whether or not "20 Questions" is a popular game in IR, and whether or not it is working. Obviously, the first change in the rules of the game is that questions are rarely (Cf. Hermann, 1969; Robinson, Hermann, and Hermann, 1969) attacked experimentally. "Natural sources" of observations have been (and probably will continue to be) the mainstay of the discipline. Aggregate, content analytic, and events data manipulated with techniques ranging from the simple correlation coefficient to factor analysis and beyond are the basic tools of the discipline. But that difference is only cosmetic. The real question is: Do we use those tools to play 20 Questions? The hallmark of 20 Questions is the framing of a general question in a binary sort of way. Examples of the binary approach in psychology are: nature versus nurture or continuous versus all-or-none learning. Newell identified 24 of them.

While the explanation of the behavior of nations is still in its infancy compared to psychology there are several respects in which the field is patterned along a binary approach. Rosenau's (1966) 'pre-theory' has resulted in a number of binary oppositions based upon nation types (e.g., small versus large states) (East and Hermann, 1974; East, 1973). The study of crisis has resulted in several binary questions (crisis behavior versus noncrisis behavior, and certain aspects of crisis behavior itself) (Hermann, 1969; Robinson, et al., 1969; Holsti, 1965, among others). Are internal factors or external factors more potent for the explanation of the foreign policy behavior of nations (Rosenau and Hoggard, 1971; Rosenau and Ramsey, 1973)? Which is more important in foreign policy: the past behavior of a nation or the behavior of another nation (Tanter, 1972)? Probably the longest running session of 20 Questions involved the relationship between foreign and domestic conflict behavior (Rummel, 1963a, 1963b; Tanter, 1966; Wilkenfeld, 1968, 1969). It must be emphasized that there is no intention of disparaging the above cited works. They have all made significant contributions to the construction of Guetzkow's (1950) islands of theory. The question really is: Is it islands of theory that we need? I think not. Nor do we need the grand-sweep, macro-type theory for which Guetzkow's islands were an alternative. The problem with the large scale theorizing is that it lacks structure. When one attempts to take a theory based upon 'the' political system with its inputs, outputs, demands, and authoritative allocations and really use it, it turns out that much of the substance of the theoretical structure, the "stuff" that holds it together, is not there. What seemed at first glance to be a hard kernal was in reality too soft and pliable. Guetzkow's strategy for dealing with this problem was to develop middle

range theories. This strategy was based upon the view that the binding force missing in the grand style of theorizing could most efficiently be built as a bridge between specific and definite islands of theory. After almost twenty-five years of building, it seems we can't get off the islands. It turns out that Guetzkow's islands of theory strategy is another name for 20 Questions. And it seems in fact that we can't play 20 Questions with nature and win.

Newell approached the problem of the identification of this binding force between the islands in this way:

> Suppose you know about an information processing system: its memories, its encodings, and its primitive operations (both tests and manipulations). What more would you require to obtain a complete picture? You need to know how the system organizes these primitives into an effective processing of its knowledge. This additional organization is called the <u>control structure</u>. (Newell, 1973b:464)

In more general terms, Newell's statement becomes: Suppose you have answers to all the binary questions you could put to nature. What more would you require to obtain a complete picture? The central point to Newell's argument is not that you can't play 20 Questions with nature. It is that you can't play 20 Questions with nature and <u>win</u>. Even if we knew that size made a difference, <u>and</u> that internal factors were more potent, <u>and</u> that for certain nation types there is a relationship between foreign and domestic conflict behavior, we still would not have a complete picture of the nation. We still would not have a science of nations "adequate in power and commensurate with their complexity." We would not know how these "facts" that we have discovered about a nation are organized to produce the behavior we observe. Newell terms this additional organization, the control structure. The control structure

specifies how all these facts about a nation fit together to produce behavior -- the system architecture. This notion of architecture can be made more explicit by taking a process view of a nation. (See Newell, 1973a and Thorson, 1975a for a further discussion.) Suppose that a nation is considered to be a decision making system. Further suppose that the decision process has been broken down into specific components or sub-processes, e.g., perception, information and alternative search, the influence of goals on choice, the choice process itself, and implementation. That knowledge alone is not enough to model a nation. You would have to know how those elementary processes are organized to form a whole. This organization is the control structure.

Newell's notion of control structure characterizes exactly what is missing in the field of international relations. That is the source of our discomfort. The grand stroke style of theorizing did not specify the control structure -- it was too abstract. Although it was hinted at in flow diagrams, e.g., Deutsch's (1966) communications model in The Nerves of Government. The island style of theorizing does not specify the control structure -- it is too specific. The grand island theorists wait for island builders to firm up their structure. The island builders wait for the grand theorists to build their bridges. Newell's solution to this dilemma is to stop waiting. He calls for his collegues in psychology to build complete processing models rather than the partial models they now construct. A complete processing model (as its name would suggest) completely models the process. This notion of completeness can be illustrated as follows: Suppose that a nation is a decision making system. That is not a complete formulation. Too much is left unconstrained and unspecified. There are literally dozens of ways to

model the decision process, ranging from economic rationality to satisficing, or even a roulette wheel. Not all of these formulations will be descriptive of the way in which nations actually make decisions. Their control structures are different. A process model is made more complete when it specifies one of these ways for modeling the decision process. A complete processing model of the decision process has completely contained within itself the capability to generate decisions. Completeness should not be confused with truth. Completeness refers only to capability. The outputs from the model may not be correct. All that is required is that the model have the capability to produce outputs characteristic of the behavior of nations. By introducing the notion of the control structure, additional constraints are placed upon the complete processing model. Not only must the outputs be characteristic of national behavior -- so must the process by which they were generated.

This explicit modeling of the control structure through the specification of a complete processing model can best be illustrated by certain uses of the technique of computer simulation. The sort of computer simulation that best captures this notion is not merely a system of equations that describes the behavior of a nation. It goes beyond description into an investigation of the internal structure of a nation. This structural approach to simulation explicitly models the control structure. A linear model may very well describe the behavior of a nation. But in that case, the control structure is by default, linear algebra. In a complete processing model with an explicit attempt to model the control structure, the internal operations of the system are theoretically descriptive of nations -- not just the outputs. From the field of psychology, the efforts of Newell and Simon (1972) are examples

of control structure simulations. In their investigation of human problem solving, they have programmed a computer to prove theorems in elementary predicate calculus logic. They have programmed a computer to play chess. It is vitally crucial to note that these efforts are not simply technical displays of computer programming proficiency. Newell and Simon have attempted not to just program a computer to play chess -- but to play chess <u>in the same manner</u> as do humans. If one takes the decision making perspective on the behavior of nations, a complete processing model of a nation not only produces outputs that bear a strong resemblance to the decision outputs of nations, the model actually makes decision "in the same manner" as do nations. While the only examples of complete processing models with a sensitivity to the control structure are simulations in the style of Newell and Simon, that surely will not always be the case. But it does seem clear that until we have grown more accustomed to thinking in terms of control structures and complete processing models, the simulations of Newell and Simon will provide the exemplar. They serve as a convenient crutch to support this new strategy in theory building during its infancy.

As was mentioned above, the basic notion of a control structure has always been close to the surface in contempory theorizing. The heuristic models consisting of boxes and arrows, information flows, and control are really very informal representations of the control structure, e.g., Figure I below. There are uses for heuristic models or conceptual frameworks. But one of them is not the representation of the control structure of a system. The modeling of control structues via complete processing models requires a much more rigorous and formal approach.

A Strategy for the Construction of Complete Processing Models

Before outlining a strategy for the modeling of control structures via simulation, it should be emphasized that no matter how promising the notion of complete processing models may look, there is a great chance (if past experience holds true) that all of this will come to naught. The "long road to theory" is strewn with conceptualizations that have been tried and disgarded. But it also must be remembered that it is through this process of conjectures and refutations that scientific knowledge grows (Popper, 1965).

There are two basic themes that will be used to develop this research strategy: 1) generative explanations; and 2) the role of computer simulations. In a generative explanation, it must be demonstrated how the behavior in question is generated (Holt and Turner, 1970; Simon, 1969). The strategy becomes one of design: What structures and processes will result in the production of the observed behavior? One has a potential generative explanation when one can exhibit a process that is sufficient to "mimic" the behavior in question. Thorson (1975b) calls these potential generative explanations, descriptive theories; Zeigler (1970) calls them behavior preserving morphisms; Newell and Simon (1965) call them sufficiency models. If it can be shown that the structures and processes are necessary and sufficient, one has a generative explanation. The process of moving from a position of sufficiency to one of necessitity and sufficiency can be characterized by the concept of retro-duction. (Hanson, 1958) Initially, one starts with a model sufficient to mimic behavior. The behavior of this sufficiency model will generally have implications beyond the model in several respects. These implications will suggest new properties and behavior which should be true of

nations. These additional implications, plus the direct comparison between the behavior of the nation and the model provide the basis for further modifications of the model. It is at this point that the binary approach noted above can be used with greater confidence. But this use of a binary approach is not the game of 20 Questions. It is different in several respects: 1) There is a firm theoretical basis provided by the complete processing model; and 2) Since there is a basic model of the control structure, the choice of one or the other of the two alternatives will have other consequences for the behavior of the system. Under this approach, it is possible to use the whole of the theoretical structure in answering the question. (For a somewhat different formulation of this strategy, see Ackoff and Emery (1972), especially chapter 13.) The issue now becomes: How does one construct these sufficiency models? One strategy, illustrated in the later portions of this paper, is based upon the notion of organizing principles. By predicating certain properties of nations the class of admissible control structures is limited. These organizing principles restrict the class of systems which are considered to model the nation. For example, suppose that a nation is characterized as a goal seeking system. This initial predication means that any goal seeking system can be taken as a model for the government. Then by explicating those properties that must characterize the model for a nation, the class of admissible (or equivalent) systems is reduced. Governments have certain properties that set them apart from a general goal seeking system. Only certain types of goal seeking system exhibit the properties necessary for the modeling of a government. For example, some of the organizing principles developed below are that nations are multiple goal seeking systems, and that governments follow a satisficing

decision procedure. In other words, any system taken as the model for a nation must be a multiple goal, satisficing, goal seeking system. In summary, this research/discovery strategy is based upon two question: 1) What must I assume to be true of a government if my model is to generate characteristic behavior; and 2) What can I not assume to characterize a government, given what I already know (or believe) to be true of a government. The first question illustrates the deductive nature of the enterprise. The second illustrates its inductive nature.

The other point, the use of simulation, plays a vital role in the strategy. Solutions come easiest when a question is well posed. Many past uses of simulation have been criticized on those grounds: Why simulate? You are using simulation as a way of generating deductions. If you had posed your problem correctly you could have an analytic solution. For many attempts at simulation, this criticism is justified. (Cf. Nordhaus' (1973) analytic solution of Forrester's (1971) World Dynamics simulation.) But it does not hold true for all uses of simulation. One response is that while it is true that simulations often represent attempts to deal with ill structured problems, the process of simulating defines those problems. In fact, Simon (1969) has argued that simulations are the ideal tool for increasing our understanding about such systems. In a sense, simulations tell us more about the system than we told the simulation about the system. In addition, Simon further argues that science is built from the roof down to the yet unconstructed foundations. This "top-down" approach works because the behavior of the system at one level depends on only a very abstracted and approximate characterization of the system on the next lower level. It is also the case that analytic solutions are not always appropriate.

For the types of problems that Newell and Simon (1972) consider, for the system that is developed later in this paper, and for generative explanations in general, the notion of an analytic solution in the traditional mathematical sense has no meaning. But the notion of a control structure does. In fact, one cannot simulate a complete processing model unless it is in fact complete in the sense of completeness used above. Is not that what is meant by a well posed problem in the first place? A problem posed completely and clearly, with no loose ends.

The remainder of this paper represents an illustration of the construction of a complete processing model of a nation. It falls into two parts: 1) the representation of a nation; and 2) the programming of that representation as a computer simulation. The perspective taken is that the nation is a goal seeking system. The next section takes this basic representation and further refines it through the process of equivalence classes of systems. The second portion is concerned with techniques and issues involved in the modeling of a complete processing model of a nation.

The Nation as a Goal Seeking Decision System: A Representation

What does it mean to characterize a nation as a goal seeking system? Simply put, the predication of the property of goal seeking to a system means that the behavior exhibited by the system is the system's attempt to steer or control (Cf. Deutsch, 1966; Simon, 1969) its environment so as to achieve a set of goals. As was mentioned above, the research and discovery strategy used here is based upon the notion of equivalence classes. Through successive iterations the class of system to which the nation is posited to belong to is refined. This refinement is essentially the identification of properties which are held to be true of nations but not of the general class of goal seeking systems. By simply including the nation as a member of the class of goal seeking systems there is the implicit statement that a servo mechanism and a nation are alike in all significant respects. There are several reasons why a nation cannot be considered equivalent to a servo mechanism. The purpose of this section is to identify and explicate those reasons.

The basic components of the adaptive goal seeking framework

----- FIGURE I ABOUT HERE -----

are: 1) the inner environment (IE); 2) the outer environment (OE); 3) the access interface (AI); 4) the observation interface (OI); and 5) the model (or image) of the OE (M). (Cf. Bailey and Holt, 1971; Simon, 1969; Thorson, 1974) The interpretation of this framework into national decision system terms results in the following names being assigned the basic components: 1) the inner environment is the government of a particular nation; 2) the outer environment consists of everything that is external to the governmental structure of the IE; 3) the observation interface are those portions of the government that are

responsible for the observation of the current state of the OE; 4) the access interface is composed of those components of the bureaucracy that are responsible for executing the actions that flow from the IE; and 5) the model is a shorthand term referring to how the various elements in the national bureaucracy responsible for the determination of decisions believe the OE works. It is important to note that the IE is defined strictly as the government. (For the purposes of this paper, we will only be concerned with the decision making aspects of the IE. The term decision mechanism represents those aspects.) In contemporary theorizing in the field of international relations it is often the case that the unit of analysis is the nation, often expressed as the "political system." This view is best exemplified by the efforts of Rummel's (1971) status field theory or Singer's (1972) Correlates of War Project. It is not claimed that the approach advocated here is strictly better than the specification of the unit of analysis as the nation. But given the types of concerns expressed and the sort of explanation and theoretical structure desired, the specification of the IE as the government seems more useful than the specification of the IE as the nation. On the other hand, there are instances where it may be more efficient to view the unit of analysis as the nation as a whole. Note that taking the government as the unit of analysis does not imply that a choice has been made between the unitary actor or bureaucratic/organizational (Cf. Allison, 1971; and Allison and Halperin, 1972) representations of the government. Both are consistent with the adaptive framework. While the work reported here does view the government as composed of several organizational actors the concepts developed are not restricted to a bureaucratic/organizational viewpoint. The second aspect that deserves

mention is the definition of the outer environment as everything external to the IE. This distinction is captured to a certain extent in Singer's (1961) discussion of the notion of levels of analysis. While this approach is a systems approach, it is not a systemic approach as characterized by Easton (1953), Kaplan (1957) or Parsons (1958). While part of the OE would, in current international relations parlance be called the international system, this is not the same international system of which Kaplan et. al. speak. The system is the national government. What is called the international system portion of the OE is Kaplan's international system, minus the nation under study. What is called the domestic political system in Easton's terms is also included in the OE in the same manner as Kaplan's system is included. There is not a priori distinction between domestic and foreign environments. While it is the case that in some ultimate sense everything external to the nation is part of the OE, considerable simplification of the size, complexity, and extent of the OE is possible. (See Simon (1969) for a discussion of the architecture of complexity.) From the perspective of the system, the model (M) of the OE will specify the causally relevant linkages. The final comment concerns the nature of the observation and access interfaces (OI and AI). Both the OI and AI are part of the IE, i.e., they are portions of the national governmental structure. Because they perform distinct sorts of functions (exhibit different classes of behavior) they represent separable components. But the access and observation interfaces themselves need not be distinct organizational members of the national governmental bureaucracy. Consider the Wage and Price Control Board. It had the responsibility of monitoring wage and price levels (observation) and it had the power to control wage and

price changes (access). But because there were two classes of behavior that the Board could exhibit (observation and control) the functions of the Board can be assigned to both the AI and OI.

At a basic level the system operates as follows: The national decision system has a set of goals for the configuration of the OE. Under the control of the decision mechanism, the OI takes observations on the OE and sends that information to the decision mechanism. The decision mechanism then compares the image it receives of the OE with the goal state. Based upon the perceived discrepancies between the goal state of the OE and the perceived state of the OE, the decision mechanism begins to search for behaviors it could emit to move the OE closer to the goal state. The decision mechanism uses its causal model of the OE to assess the degree to which a given behavior or set of behaviors will increase the level of goal attainment. When the decision mechanism discovers a set of behaviors it deems acceptable, it instructs the AI to emit those behaviors. Because of the manner in which the decision system uses its causal model, both the behavior and structure of the OI and AI are affected by the content of the model. The OI will only be sensitive to those features of the environment the M has identified as important. The behavior of the AI will obviously depend to a great deal upon the content of the M (in addition to the search procedure and the acceptability criteria used by the decision mechanism). The M will influence the behaviors the AI will emit and the sorts of behaviors the AI must have the capability of emitting. The behavior of the system is an endless loop: perceive, compare, decide, react, perceive, ..., et cetera.

The basic process has been explicated. Now the operation of the system will be examined more closely for the purposes of 1) putting some constraints on the operation of the various components; 2) highlighting the effect of those constraints on the operation of the system as a whole; and 3) increasing the specificity of the sub-class of goal seeking systems to which the nation belongs.

While it is known that the operation of the OI and the AI are by no means unproblematical -- the bureaucratic politics "paradigm" (Allison, 1971; Allison and Halperin, 1972) is centrally concerned with the contingent character of these processes -- it simplifies the discussion greatly to make this assumption. Since we have made these simplifying assumptions about the nature of the interfaces, we are now in a position to begin talking about the decision process and the role of environmental images or models in the operation of the decision mechanism. There are three steps in the operation of the system yet to be specified: 1) A comparison of the degree of difference between the observed and goal environments; 2) The use of the decision mechanism's image of the environment to "predict" changes in the environmental state as a function of the behavior of the AI's; and 3) A choice of AI actions based upon some sort of "maximization" criteria applied to goal achievement.

We really aren't sure what calculus decision makers use in determinating goal achievement. Common sense would indicate that the decision mechanism is not physically capable of considering all goals at the same time. In fact it could be argued that the OI is only capable of scanning a proper subset of the variables the decision mechanism would like to scan. Since the system cannot be equally cognizant of all goals and their associated environmental indicators, at any given point in time

the decision mechanism must in some manner select those goals to which it will be attentive. The question becomes: By what process are certain goals selected for more attention than others? Notice that for a simple decision mechanism, a servo mechanism for example, there is only one goal. In this case the process of goal attentiveness or the definition of a preference ordering of all environmental states is straight forward. Consider a servo mechanism attached to the motor of a phonograph turntable. The goal is a rotation speed of 33 1/3 revolutions per minute. The environmental state is the actual speed of the rotation. The servo mechanism can easily define a preference ordering over all environmental states. Tc further simplify the example let us suppose that the mechanism finds any speed other than 33 1/3 revolutions per minute equally undesirable. The system finds the decision as to which environmental variables to monitor and which goal to be attentive to unproblematical. The servo mechanism has the task of monitoring the speed of the rotation of the turntable (or some analog of it) and adjusting the speed accordingly. In a situation where the system is faced with two or more goals, it must somehow determine a preference ordering over all of the possible environmental states. Consider the case of a person in the midst of an energy shortage. The individual has two goals -- save energy and maintain a certain level of comfort. (The fact that these goals can be considered mutually exclusive makes the point clearer but does not imply that this relationship holds only in the case of mutually exclusive goals.) The issue the individual must face is whether saving energy or staying warm is more important. Is the dissatisfaction greater when the room is cooler than desired, but more energy is being saved -- or when the room is comfortable, but energy is

not being conserved? The question is not merely so simple as it was when there was only one goal.

Even though the problems outlined above have not been solved, let us assume that some suitable preference ordering over all environmental states has been achieved, i.e., we know how the decision mechanism evaluates the various possible mixes of environmental states. The next topic that will be considered will be how the decision mechanism "decides" what is the "best" way to decrease goal dissatisfaction. The major assumption or observation about the ability of humans to make decisions that is crucial to this element of the process is: humans do not have the capacity to consider all of the possible variables they could manipulate; they do not have sufficient information at their disposal to accomplish the task, even if they had the power to do so; and finally since a decision mechanism must depend upon its fallible model of how the OE works, even if it had all of the information and the ability to process it, the *decision mechanism does not know enough about how the world works to make a "best" choice.* One of the first to recognize that humans were not the "all powerful and rational beings" that much of decision theory held them to be, was Herbert Simon. Simon (1955) introduced the notions of satisficing and bounded rationality as descriptions of how men really behaved. Under Simon's conception of the decision process, decision makers did not search until they found the optimal solution, but rather they looked until they found one that they thought was good enough. Once they found a solution that satisfied their minimum criteria of acceptance they stopped looking. This notion of the decision process seems very close to the manner in which decision makers seem to behave. Using this satisficing notion for the basis of the operation of

the search and decision procedure, there are two basic interpretations that can be used as the basis for a decision algorithm. The first is that the decision mechanism searches for alternatives to the current policy mixture only if the dissatisfaction is above the satisficing limit. The second is that the decision mechanism always searches for alternatives when there is any degree of goal dissatisfaction. Using this representation, the decision mechanism always searches. But if the goal achievement is below the satisifcing threshold, the search for alternatives will be more encompassing and further reaching. These two basic search and selection algorithms use the notion of an absolute satisficing limit. They can both be reinterpreted in a relative sort of frame of reference. Thus the satisficing limit might be: Decrease the current dissatisfaction by 30%. The decision mechanism would search for a relative increase in goal achievement rather than an absolute level. Regardless of which of the four procedures are used as the basis for the algorithm, the system must have some sort of time or length of search limit. The time limit criteria is needed for those cases when the decision mechanims is unable to locate a set of inputs that would be expected to bring the goal achievement up to some acceptable level. Since it is assumed that there is some urgency associated with the decision process, the decision mechanism must produce some outputs. When the time or length of search limit has been reached, the decision mechanism will take the best alternative it has uncovered up to that point and use it, hoping to find something better next time.

Once the decision mechanism has decided whether or not it is going to search, and how broadly it is going to search, the decision mechanism is faced with finding a set of outputs that will increase the current

level of goal achievement. The decision mechanism searches for sets of output values for the variables that it "thinks" are important and checks, by means of its model, whether or not it can be reasonably expected the outputs will achieve their intended consequences. In effect the system generates the expectations of what the OI will be sending it on the next decision cycle, contingent upon that particular set of inputs being applied to the OE. If the proposed solution takes (or at any rate the decision mechanism thinks it takes) it further away from its goal, the decision mechanism will try a different route. On the other hand, if the mechanism perceives that a particular class of the manipulable variables is taking it closer to its goal, it will continue search in that same direction. Since the model is not perfect it will make mistakes. One would expect that since the decision mechanism has some idea of how the world works, its search for variable values would not proceed in an entirely random basis. Derived from the model and experience would be some expectations as to the effects of various outputs on the behavior of the OE. It would be expected that the decision makers would use these expectations as a guide in their search. It will not always be the case that the decision mechanism proceeds in a totally "rational" fashion. If the basic model that the mechanism uses to "think" about the OE is bad, inconsistent, or largely unspecified, the search behavior would be expected to be influenced accordingly. Another factor that would influence the pattern of search behavior would be the complexity of the conceptual model. A model, fairly complex and sensitive to the various inputs the decision maker can feed it, would be expected to result in a very different pattern of search behavior than would a model based upon some very gross and crude

notions about how the world works. As was mentioned above, the decision maker will continue searching until either one of two things happen: 1) A proposed input mixture brings the goal satisfaction below some level; or 2) Some sort of time or length of search limit has been reached.

It is important to note that at the beginning, this discussion considered a government as a member of the class of goal seeking systems. While the government is still considered to be a goal seeking system, several properties of governments set them apart from the general class of goal seeking systems. The government is a member of the class of goal seeking systems that have these additional properties: 1) They are multiple goal seeking systems; 2) They operate under one of the satisficing search and selection algorithms; and 3) They react to a perceived environment. As was noted above, this search for equivalence classes through the explication of the control structure is central to the process of discovery used here. While a fair amount of the control structure for national goal seeking decision systems has been identified up to this point, there are several aspects of the operation of the system that have not been discussed. Probably the most important of which are the notions of learning or the internalization of past experience, the structure of the causal model of the OE, the manner in which the decision mechanism internally represents its knowledge about the OE, the manner in which the AI and OI interact with the OE, and the process of perception. In addition, the bureaucratic aspects of the operation of the decision mechanism have not been dealt with. Instead of continuing the discussion of the aspects comprising the control structure of a government modeled as a goal seeking system, the discussion will now turn to consider techniques and approaches to the realization of the system and its control structure as a set of rules -- a computer program.

The Realization of the Control Structure

At first it might seem that this shift in emphasis from a discussion of the control structure to a specification of the control structure is inappropriate. There are several reasons why this is not the case. The primary reason rests upon the relationship between the explication of the control structure and its realization, a computer program. In rough terms, a representation is a conceptual model. A realization is a computer program. To help illustrate this relationship, consider another type of representation of the nation, Richardson's (1960) arms race models. In the case of Richardson's differential equation model of thez nation, the representation is the realization. The behavior of the nation in Richardson's case is represented as a differential equation. That representation can be directly manipulated. No additional translation of the representation is required before it can be manipulated, i.e., produce implications. In the present case the representation (the government as a goal seeking system) and the realization (a computer program that behaves like a goal seeking system) are not the same. One cannot diretly manipulate the notion of a goal seeking system. Because the representation is not directly manipulable and because the realization of the representation is crucially dependent upon the control structure, the specification of the system in terms of a computer program turns out to be almost as theoretically relavent as is that which is represented. In other words, how the system is represented becomes a theoretically important question. It is often the case that the implications of the relationship between representation and realization are, if not ignored, at least not fully discussed. When mathematical tools are used for the manipulation of symbols, invariably certain simplifying

assumptions are used to aid in the anlaysis. The stipulation that certain relationship are in a specific form (e.g., a quadratic or linear function) or the assumption of certain properties (e.g., a normal distribution or interval level measurement) are all assumptions that are dictated by the mathematical structure. They are assumptions made for the purposes of expediting mathematical manipulations. Bush and Mosteller (1955:46) provide a typical example:

> The form of these operators is dictated chiefly by mathematical considerations -- linear operators are chosen in order to make the theory more managable.

When one is concerned with modeling the control structure via complete processing models, the form of the operators becomes a theoretically important question. Since the form of the operators is a theoretical statement, they should not be dictated chiefly by mathematical considerations. By making the realization just as important as the representation (from a theoretical perspective) they both must be considered at the same time. They cannot be separated. One portion of a theory cannot be closed, with the expectation that the other arbitrary portion to fall meekly and consistently in line. There are crucial interdependencies at work. It is with a sensitivity to theses interdependencies that we now turn to a consideration of the techniques for the realization of the control structure as a computer program. The approach is composed of two related notions: 1) a structure for expressing the process models; and 2) the role of a language in the behavior of the system.

Production Systems: A Theory and Language for Process Models

Allen Newell has stated in another context that in order to "predict [the behavior of] a subject you must know: (1) his goals; (2) the structure of the task environment; and (3) the invariant structure of his processing mechanisms." (Newell 1973a:293) The notion of goals has been discussed previously. The structure of the task environment is identical to the manner in which the system perceives the environment it is attempting to control. Production systems represent a means for expressing the third element in Newell's list--the structure of the processing mechanism (the control structure).

Production systems represent a form for describing processing models -- a theory laden programming structure. Production systems explicitly incorporate theoretical assumptions, and provide a means of expressing the control structure explicitly. In fact they force one to be explicit about the control structure by making it an integral part of the specification of the process. Production systems have been used extensively in psychology (Newell, 1973b,1966; Newell and Simon, 1972) for the expression of theories of human problem solving.

From a practical programming point of view, there are several programming languages which could serve as the basis for the specification. But as will be developed below, a production system is a very simple, yet very powerful structure. Much more so than, say FORTRAN. More importantly, production systems themselves are a control structure. (See Newell, 1973a) No attempt is made here to defend production systems against other possible formulations of a control structure. Production system do allow very natural interpretations of the control structure of a government. Production systems make a theoretical statement -- FORTRAN can make no such claims.

Processing models written as production systems are formed by a collection of independent rules, called productions. The rules (or productions) are stated in the form of a condition and an action: C → A. The condition refers to the symbols in the short-term image (STI) of the system. The STI represents the system's transient image of the current state of the OE. The actions of the productions consists of transformations on the STI "including the generation, interpretation, and satisfaction of goals, modification of existing elements, and addition of new ones." (Klahr, 1973:528) A production system obeys simple operating rules:

i. The productions are considered in sequence, starting with the first.
ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in STI. If all of the elements in a condition can be matched with elements (in any order) in STI, then the condition is satisfied.
iii. If a condition is not satisfied, the next production rule the ordered list of production rules is considered.
iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).
v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.
vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.
vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost. (from Klahr 1973:528-29)

While a production system may appear to be deceptively simple (if not simplistic), there is a reservoir of analytic power underlying that simple structure. Post (1943) has proven that any Turing machine (a very powerful and abstract computer) can be modeled as a production system. But even more importantly, there is a one-to-one correspondence between the elements of a Turing machine and a production system. Thus it may

be possible by reformulating the production system as a Turing machine quintuple to use the analytic structure upon which Turing machines are built as an additional means of exploring the implications of the model.

The illustrative production system in Figure II is a highly stylized

-----INSERT FIGURE II ABOUT HERE-----

system that attempts to describe the behavior of the Libyan Revolutionary Command Council. (Although it should be noted that in terms of complexity and the resolution of the issues raised in this paper, the system in Figure II bears about as much resemblance to our goal as a flowchart for making fudge resembles a program.) Recently Kaddafi was asked to step down from his political-diplomatic position but retain his position as Commander-in-Chief of the Libyan armed forces. The example production system is an attempt to specify those conditions under which the Council will request that Kadaffi step down (or go to the desert for meditation). This production system was built upon the assumption that the reasons Kaddafi was asked to step down amount to the perception on the part of of the members of the Council that things are not going well for Libya. Some of the indicators or monitor variables that the Council might consider are: fiscal irresponsibility, food shortages, excessive religious orthodoxy. It was also assumed that the Council was more willing to ignore some of the bad points if there were favorable aspects of the situation to offset the bad points (or as they are expressed in the production system, marks). Thus if Sadat looses face, there is an increase in skilled labor, or if there is a food surplus (relatively), the council will overlook some of the bad points about Kaddafi's management. If it is the case that e[illegible] with the good points, Kaddafi has

managed to accumulate four marks, the Council will request his resignation. The actual operation of the production system is as follows: Initially the STI of the Council is filled with NIL or blank symbols. Since none of the first 15 productions will be satisfied, the sixteenth production, which contains no condition is satisfied. The action READ means that the Council looks at the environment and takes a reading of the current state. As long as the symbols read from the environment does not invoke a production, the system will continue reading until one is found. Let us say that the first "recognizable" symbol is a food shortage. After it is placed in the STI by the READ operation, production 5 will be executed. This results in FOOD SHORTAGE being marked as OLD. The OLD(**) operator is a replacement or masking operation. The application of OLD(**) to the symbol $$$, results in $$$ being replaced by OLD($$$) in the STI. OLD(**) operates on the symbols of the conditional portion of a procution. This prevents the system from counting FOOD SHORTAGE twice, since FOOD SHORTAGE and OLD(FOOD SHORTAGE) are not the same. The production also results in a MARK being placed in STI. If at any time, Kaddafi has supported four radical foreign causes with no noticable achievement, production 7 is executed, which results in all four supports of radical foreign causes being marked as old, and the addition of a MARK to the STI. If it happens that there is an increase in skilled labor when there is also a MARK in STI, both the skilled labor increase and the MARK are masked. In essence, one of the strikes is erased although it still takes up a position in the STI. If at any time, Kadafi has managed to accumulate four MARKS, the symbol REQUEST will be placed in STI. This results in the Revolutionary Command Council asking Kadaffi for his resignation.

One of the striking things about production systems is that the order in which the productions are ordered has very real consequences for the operation of the system. Notice that all of the productions that erase 'marks' from the STI are at the end of the system. This means that a mark can only be erased if there are no 'bad things' in the STI. If the set of productions that erased marks were to be moved to the top of the system, the chance for an erasure would be greater (and the chance for removal less). If production 3 were placed at the end, the only time that Kadaffi would be asked to step down would be when neither anything good nor bad was happening. If it were inserted after production 11, the only time that he would be asked to go the desert is when he had accumulated four strikes, and at the present time all was going well, i.e., the short-term image was filled either with junk or positive symbols. Depending upon the sorts of things that the Council could be expected to receive from the environment, by rearanging the individual productions, the chance that Kadaffi would be requested to step down could be varied. Thus it is not enough to say that fiscal irresponsibility and food shortages count against Kadaffi in the eyes of the Council. One must be more specific about exactly what the conditions are that will cause the Council to request his removal.

As an example of a production system with more theoretical interest, consider the example in Figure III. This illustration is a portion of

-----INSERT FIGURE III ABOUT HERE-----

a larger production system that attempts to model the behavior of the Ministry of Agriculture of Saudi Arabia. The portion of the system illustrated here is concerned with the relationship between land and labor productivity (information from the observation interface) and

allocations of land, labor, mechanization, fertilizer, and irrigation water (actions of the access interface). This portion of the production system results in the generation of general policy guidelines. These general policy recommendations serve as inputs to another portion of the system responsible for translating these general directives into specific levels of fertilizer, etc. It is worth noting that the conditional portions of the production system (low labor productivity, for example) are not represented in the system as a number -- they are linguistic expressions. The observation interface generates a sentence describing a quality of the OE. The production system operates upon that sentence (as well as the specific level the linguistic expression represents) in the generation of a decision. This linguistic aspect of the system will be discussed in more detail below.

This completes the general discussion of production systems. Before proceeding with the discussion of the role of language and the notion of a grammar, there are several aspects of the specification that deserve note. Since production systems are being used for the realization of a government, the capabilities of the production system must be characteristic of the capabilities of a government. Among other things this implies that: 1) The production system have the capability to perceive and misperceive the current state of the OE; 2) The production system must take incoming messages from the environment and interpret them according to the beliefs, presumptions, presuppositions, and biases peculiar to the decision makers in a given country; 3) The production system must have the capability to rewrite the goals of the system; 4) The production system must have the capability to change the perceptual coding rules; 5) The production system should invoke a cognitive map or

image of the environment in its attempts to determine appropriate actions; and 6) The total production system should be modeled to reflect the bureaucratic/organizational aspects of the decision process. In short, the production system must have the capability to make decisions.

The Role of Language and a Grammar

When we communicate with another person or a computer we do so by using a set of symbols that we both are able to perceive. In addition, only certain strings of those symbols make sense (or convey the intended meaning). We can't communicate with a computer by shouting at it, since it cannot perceive our attempts to communicate. In addition we can't tell it just anything, since it has the capability of making sense out of very specific strings of special symbols. The system that we use to communicate with is called a language, the symbols are elements of the alphabet of that language, and the rules for forming possibly intelligible strings of symbols is called a grammar. The grammar will not insure that the meaning that was intended is actually conveyed, since others can misinterpret what we had intended. In addition, grammatical sentences can have absolutely no meaning what so ever. The sentence: "Colorless green dreams sleep furiously." (Chomsky, 1957) might be considered a grammatical sentence but it conveys no meaning.

Since nations communicate with each other, any complete processing model of a nation must also include this capability. Using these notions of language and grammar, a language could be used for the communication of the behavior of the national decision systems. Governments would communicate with each other by sending sentences in a language. The output from the simulation would be a list of sentences. For example: Since Israel cannot resist Egypt if Israel is not resupplied, the U.S. will resupply Israel. The Arabs could respond by saying: We will not provide the U.S. with oil because of its resupply of Israel. A language could serve as a medium for communications within a government: If we do not give the U.S. oil, it will not encourage Israeli aggression.

These notions of grammar and language are really not as alien to the field of international relations as first might be imagined. One of the main sources or types of data that has been used in the field is events data. (McClelland and Young 1969; Hermann et. al., 1974; Burgess and Lawton, 1972). Events are actions by national decision systems, and events data simply represents the coding of these actions a single coding scheme, generally of the form: action, actor, target. Language is a coding scheme. It is the representation (coding) of meaning according to a set of rules (a grammar).

This approach to the representation of action differs from the standard events data approach in two respects. The first difference is in the level of detail (the information content of the event). A common event coding category is official diplomatic protest. While there has been some effort to also include in the coding scheme the context of the protest, in all cases almost all of the actual content (what the protest was about) has not been coded for analysis purposes. While it is possible to conceive of situations in which one could make sense out of correlations between event type categories, it seems virtually impossible to begin to build a process model of international relations in which the only means of communication between the various national bureaucracies is by contentless statements. In order to go beyond the type of theorizing that says: if a nation receives a diplomatic protest it will respond with an unofficial warning and an armed force mobilization, exercise and/or display (to use two of the categories from WEIS), a different sort of language will be required. That language must have content (meaning) as well as form (the type of action). Since the assumption that governments are goal seeking systems is taken seriously, it is imperative

that the language that governments "talk" with be able to express the goals of the decision makers. While Callahan's (1974) analysis of the goals of the five oil producing nations identified a wide range of goals, none of the goals he identified were of the form: "Decrease the number of formal diplomatic protests by three-fourths." A language is needed that is capable of expressing a much richer content than any of the existing event category schemes are capable of providing.

The second difference between typical events coding and this language building effort stems primarily from the assumption that nations perceive incoming messages within the context that they are generated. The standard approach followed by all existing events data efforts is the use of the coding category for the interpretation of actions. There is an explicit attempt to make perceptual decisions. Common categories include threats, accusations, and rewards. Since nations operate on a perceived OE, the perception of the meaning of the actions must be the responsibility of the decision system. What is a negative deed from the perspective of one nation may be a very desirable action as far as some other nation is concerned. This perceptual role in the standard approach to the recording of international interactions is handled by the coders, who are assigned the responsibility of making the distinction between a threat and a promise. (A threat is really nothing more than a promise with a negative consequence.) The simulated governments must make that distinction.

If the language is to be a neutral affair intended only for the transmission of ideas and not predetermined perceptions by some third party, the language must be structured so as to avoid the gross preprocessed perceptual categories of the standard events data approach. This

implies that the basic units of the language should be statements of action rather than perceptual categories. It will then be up to the perceptual portion of the decision system to parse the action message into its own cognitive map or conceptual categories. This is not to say that the word "threat" cannot appear in the language, but that it will be the job of the decision system to determine whether an action really is a threat, the consequences the action will have on the goals for the system, as well as the credibility of the action. This conception of the role of the language has some implications for the structure of the language, the second distinction between events coding schemes this approach. The manner in which "events people" have approached the structure of their coding categories is to devise a mutually exclusive and collectively exhaustive typology for the classification of international interactions. In essence they have listed all of the possible sentences in their language. They then look at the event or interaction and determine which of the sentential forms fits the action. This approach differs from the event approach in that rules for generating sentences in the language are specified rather than listing each possible sentence individually. If one has a small language consisting of only a few sentences, the list approach has some merit. On the other hand, if the language is large and capable of expressing a wide variety of sentences, some of which may be appropriate only in certain circumstances, the exhaustive listing of all sentences may be impossible. Immagine this situation: Suppose you are a proofreader, and it is your responsibility to insure that this paper contains only grammatical sentences. Further suppose that you have no knowledge of the grammar of the English language. Your only means for determining if a sentence is grammatical is to

look it up in a book that purports to contain all possible grammatical sentences. Now imagine that you have a set of rules for determining the correctness of a sentence. With those rules (the grammar) the job is vastly simplified. The way that formal linguists generally express it is that a grammar is the set of rules specifying admissible manipulations (stringing together) of the words of language. By taking a finite set of words and a finite set of rules, it is possible to generate an infinite number of sentences. The advantages of listing the rules over listing all possible sentences is substantial. By basing the language on a modest set of objects (actions and actors) and on a small set of rules, a rich language can efficiently be specified. A language of greater precision, breadth, depth, complexity, and richness than could be hoped to listing all possible sentences. It will result in a more complex, conceptually leaner, and theoretically powerful system for expressing the behavior of a nation than an event coding typology could ever hope to generate.

Very large demands are being placed upon the language. It must be able to describe a context that will allow the perceptual system of the decision modules to determine meaning; it must be able to describe the current state of the environment so that a decision can be made; it must be a medium by which the actions of a government can be transmitted between and within governments. In fairness to those who have taken the events coding approach, it should be mentioned that these demands upon the language are much more severe than those of the events people. They wish only to describe very gross types of behavior, while we have to express not only the type of behavior, but also the substance of the act. While severe demands are made of the language, because of the

conceptual power of the approach to language building through a grammar, the task in some ways is simplified. Because of the nature of the approach the entire problem can be broken down into separable (not separate) clusters. Rather than being forced to consider the language as a whole, it can be broken down into the problems of a grammar, sentential forms, and objects.

As an example of the power of the approach, consider the rough specification of a language in Figure IV. The structure specified in

-----FIGURE IV ABOUT HERE-----

Figure IV is not the specification of a grammar. It only gives 20 basic sentential forms. It is the structure of a language -- not a specification. The structure could become a specification with the inclusion of a set of actors and actions. But even on a structural level, the language reveals a considerable degree of power. Sentence forms 3, 4, 5, 6, 12, and 13 are sufficient to generate a language of greater complexity than the 63 WEIS coding categories (McClelland and Young, 1969). For example sentence 12 could be represented as a threat, promise, the offer of a proposal, a demand, a warning, or an ultimatium (to use some fo the WEIS categories). In addition, the six forms alone can generate sentences of greater complexity and sophisticaion than WEIS or any other coding scheme can specify. For example: Since X will not do A then if X does B, Y will do C. This sentence structure represents the embedments of sentence type 1 in type 6. It is this ability of a grammar to define embedments in a recursive manner that accounts for its generality and power. As a further indication of both the power of the approach and the demands being placed upon the language, suppose that the OI for Saudi Arabia receives these three sentences:

1) The total wheat crop is X bushels.
2) Y men are employed in farming.
3) "Since Israel cannot continue to resist Egyptian aggression if it is not given replacement materials, we [the U.S.] will begin the immediate resupply of Israel."

The perceptual system of the Saudi production system should be able to produce these eight sentences as outputs:

1) Labor productivity is low.
2) The U.S. will resupply Israel.
3) The U.S. is ignoring our threat of an oil embargo.
4) The U.S. is still pro-Israeli and anti-Arab.
5) The U.S. is supportive of Israeli behavior.
6) The total wheat crop is X bushels.
7) Y men are employed in farming.
8) Labor productivity is Z bushels per man.

This example makes extremely strong demands not only upon the language but also on the production system. But because of the basic power of both production systems and languages the demands are not overly severe.

One of the side pay-offs of this effort at specifying a language for the communication of the decisions of national decision systems is the potential linkage with current events data collection efforts. While the basic approach is somewhat different, there is a very important linkage between the two types of efforts. The decision systems will generate a data source expressible in an event type coding typology. The system should be able to generate the raw data of events data collection efforts. This fact has two important implications: 1) this approach is not alien to much of the work now being done in the field of international relations; and 2) existing events data collections can serve as an important source of validating data. It should be possible to take the output from the simulations (sentences in the language) and code them according to an events coding typology. That coding could be compared to current data sets to assess the amount of agreement. This

interface between events data and our efforts at the specification of language also has the implication that goal seeking propositions could be translated into event type propositions. In addition, the result of these efforts should serve as the basis for a strong theoretical grounding for an even coding scheme. There is a potential source of mutual benefit.

Summary, Overview, and Concluding Comments

This paper has covered a wide variety of topics -- ranging from a game called 20 Questions to a consideration of grammars. Through out the course of the development, assertions have been made which must be supported, and promises have been made which must be kept. Some of the assertions concern the nature of the scientific enterprise:

(1) The binary approach to the construction of theories will not work.

(2) The binary approach will not work because there is not a specification of the control structure.

(3) One promising approach to the modeling of control structures is the construction of complete processing models.

(4) There exists a definate and workable strategy for the construction of complete processing models, based upon the use of generative explanations and simulations.

Others concern the specific approach illustrated in the later portions of the paper:

(5) A government can be faithfully modeled as a goal seeking system.

(6) A production system can be specified that will produce behavior characteristic of the behavior of governments.

(7) A language suitable for the expression of the behavior governments can be specified.

(8) A production system, that corresponds to point 6, can be specified as a language processor.

These last four are the promises.

Currently, work is under way toward the fulfilment of those four promises. While the implications that I draw from the binary approach are not necessarily shared by my collegues, the last four promises are the central core of our work. While there is much to

be done, the fact that separable issue clusters have been identified should promote the attainment of the final goal -- a science of nations adequate in power and commensurate with their complexity.

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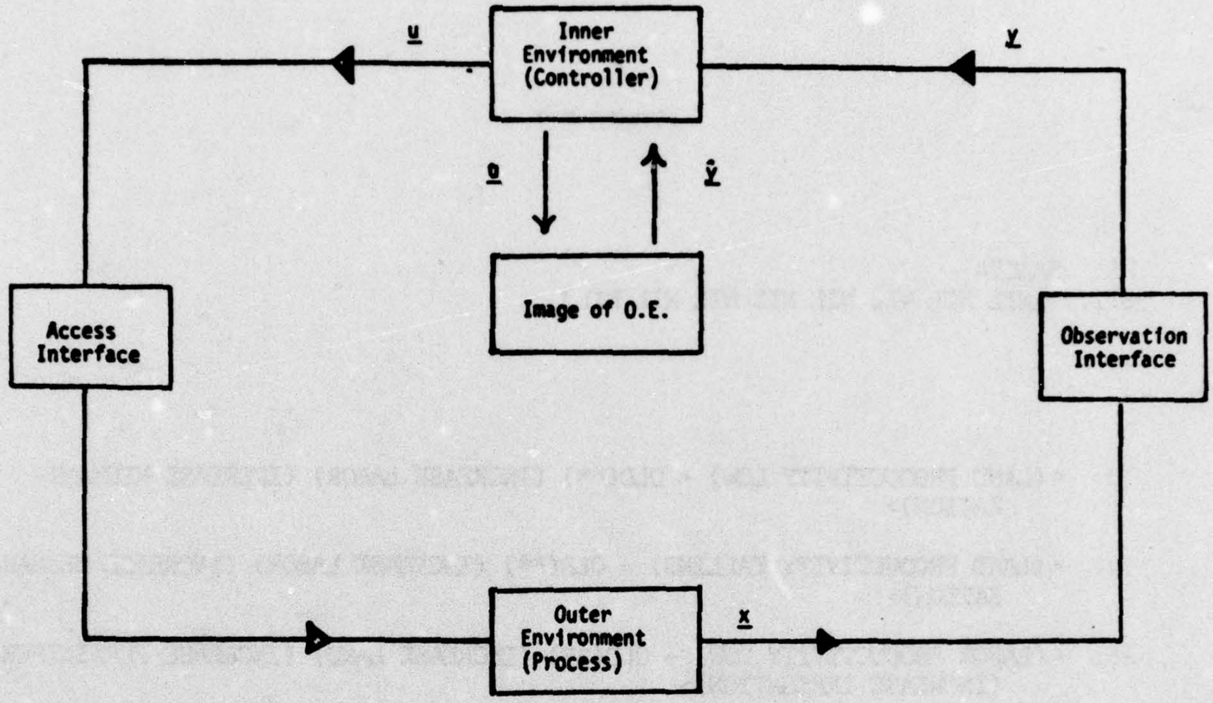

Figure 1 Artificial System Structure

```
PS:  LRCC74
STI: (NIL  NIL  NIL  NIL  NIL  NIL  NIL  NIL)

1:  (STOP) → END
2:  (REQUEST) → (OUTPUT  "RESIGNATION", STOP)
3:  (MARK,MARK,MARK,MARK) → (OLD(**),REQUEST)
4:  (FOOD SHORTAGE,FISCAL IRRESPONSIBILITY,NEGATIVE FOREIGN
        COMMENT BY AN ALLY) → (OLD(**),REQUEST)
5:  (FOOD SHORTAGE) → (OLD(**),MARK)
6:  (SUPPORT OF RADICAL FOREIGN CAUSES,NO ACHIEVEMENT) →  (OLD(**),MARK)
7:  (SUPPORT OF RADICAL FOREIGN CAUSES,SFRC,SFRC,SFRC) →  (OLD(**),
        FISCAL IRRESPONSIBILITY)
8:  (FISCAL IRRESPONSIBILITY) → (OLD(**),MARK)
9:  (NEGATIVE FOREIGN COMMENT BY AN ALLY → (OLD(**),MARK)
10: (BAN CIGARETTES or BAN ALCHOHOL or BAN LUXURIES) →
        (OLD(**),ORTHODOXY)
11: (ORTHODOXY,ORTHODOXY,ORTHODOXY,ORTHODOXY) → (OLD(**),MARK)
12: (FOOD SURPLUS,MARK) → (OLD(**))
13: (SUPPORT RADICAL FOREIGN CAUSES,ACHIEVEMENT,MARK) → (OLD(**))
14: (INCREASE IN SKILLED LABOR,MARK) → (OLD(**))
15: (SADAT HAS TROUBLES,MARK) → (OLD(**))
16:  → READ

* SFRC = SUPPORT OF RADICAL FOREIGN CAUSES
```

Figure 2 A Simplified Production System

FIGURE III

PS: SAAC74
STI: [NIL NIL NIL NIL NIL NIL NIL NIL]

.
.
.

13: <(LAND PRODUCTIVITY LOW) → OLD(**) (INCREASE LABOR) (INCREASE MECHANI-ZATION)>

14: <(LAND PRODUCTIVITY FALLING) → OLD(**) (INCREASE LABOR) (INCREASE MECHANI-ZATION)>

15: <(LABOR PRODUCTIVITY LOW) → OLD(**) (INCREASE LAND) (INCREASE FERTILIZER) (INCREASE IRRIGATION)>

16: <(LABOR PRODUCTIVITY FALLING) → OLD(**) (INCREASE LAND) (INCREASE FERTI-LIZER) (INCREASE IRRIGATION)>

17: <(LAND PRODUCTIVITY HIGH) → OLD(**) (INCREASE LAND) (INCREASE FERTILIZER) (INCREASE IRRIGATION)>

18: <(LAND PRODUCTIVITY RISING) → OLD(**) (INCREASE LAND) (INCREASE FERTILIZER) (INCREASE IRRIGATION)>

19: <(LABOR PRODUCTIVITY HIGH) → OLD(**) (INCREASE LABOR) (INCREASE MECHI-NIZATION)>

20: <(LABOR PRODUCTIVITY RISING) → OLD(**) (INCREASE LABOR) (INCREASE MECHI-NIZATION)>

.
.

AN AGRICULTURE CONTROL

PRODUCTION SYSTEM

FIGURE IV

1: <ACTOR> <CAN|CANNOT> <ACTION> <ACTOR>*

2: <ACTOR> <COULD|COULD NOT> <ACTION> <ACTOR>*

3: <ACTOR> <WILL|WILL NOT> <ACTION> <ACTOR>*

4: <ACTOR> <SHOULD|SHOULD NOT> <ACTION> <ACTOR>*

5: <ACTOR> <DID|DID NOT> <ACTION> <ACTOR>*

6: <ACTOR> <IS|IS NOT> <ACTION> <ACTOR>*

7: WILL <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

8: SHOULD <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

9: DID <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

10: IS <ACTOR> <DOING|NOT DOING> <ACTION> <ACTOR>*

11: CAN <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>*

12: IF <•••> THEN <•••>

13: SINCE <•••> THEN <•••>

14: <•••> BECAUSE <•••>

15: <•••> SO THAT <•••>

16: <•••> AND <•••>

17: <•••> OR <•••>

18: <•••> IF <•••>

19: <•••> AND NOT <•••>

20: <•••> OR NOT <•••>

* Optional; the actor (target) may be omitted.
| means that one of the two choices should be selected.
••• means that any one of the 20 sentential forms may be selected.

Some Comments on the State of
General Systems Theory*

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SOME COMMENTS ON THE STATE OF GENERAL SYSTEMS THEORY

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CACI, INC.

ABSTRACT

This paper presents a review of three major problems in the current development of General Systems Theory as represented by J.G. Miller's Living Systems. The three topics deal with: (1) the analytic representation of the adaptive nature of complex systems, (2) the hierarchical nature of information and authority in complex systems, and (3) the dynamic nature of the decision problem. Each topic is developed in terms of recent additions to theory in the systems approach.

James G. Miller has suggested that a "general systems theory" can be developed by abstracting properties peculiar to physical, biological, and social systems.[1] The primary emphasis of this approach is on ascertaining the substantive properties shared by the various systems.[2] This attempt, however, has not been altogether successful. In part, success depends upon the state of the art in each discipline corresponding to the level of analysis upon which the theory focuses. Serious difficulties have arisen at the more macro-systems level, particularly in political science and international relations. General Systems Theory embraces the notion of teleology at most system levels; but the versions of General Systems Theory practiced in political science and international relations tend to strip away the heart of the formulation leaving, in most cases, an empty input-output shell with which to work. This is due, at least in part, to the rejection of the structural-functional approaches to political development. It may also be the result of a lack of understanding of the need for decision algorithms or goal-seeking apparatus in General Systems Theory. This shortcoming stems primarily from a lack of formal development of the systems theoretical approach. The concepts developed in that approach are too often furthered by the use of analogy and metaphor. This paper is an attempt to examine some of the major concepts which, in recent years, have been developed beyond the level of sophistication present in the current versions of Living Systems and the whole General Systems Theory perspective. It will deal with systems at the national level and reference both national and supernational systems.

THE ADAPTIVE NATURE OF COMPLEX SYSTEMS

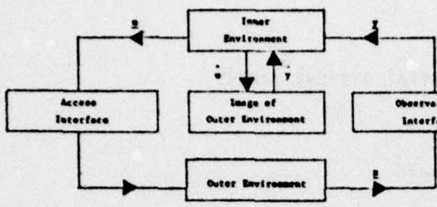
Systems of the nature we are examining are artificial or adaptive in a very specific way.

> They are as they are only because of a system's being molded, by goals or purposes, to the environment in which it lives. If natural phenomena have an air of "necessity" about them in their subservience to natural law, artificial phenomena have an air of "contingency" in their malleability by environment (Simon, 1969: ix).

An adaptive system is one that produces (generates) outputs in such a manner as to attain or seek to attain certain goals. Adaptive systems respond to environmental changes by altering policies so as to minimize the discrepancy between policy outcomes and predetermined goal states.[3] In the area of energy policy, for example, a goal might be to maintain present demographic distribution patterns in a particular region, perhaps Western Europe. Faced with environmental changes that reduce the availability of crude oil, then, an adaptive system might seek to convert electrical production from a procedure based on oil to one based on coal while retaining high levels of gasoline production. If this policy allows continuation of suburban and rural living and lengthy commuting, the system has successfully adapted to this environmental change.

Adaptive systems have a number of components. There is an inner environment (I.E.) which attempts to achieve goals in an outer environment or task environment (O.E.). The inner environment receives information (reduced quantity of crude oil) about the outer environment through an observation interface. Similarly, the inner environment implements its decisions (alters electrical production functions) through an access interface. In order to evaluate alternative policies without actually implementing them, the inner environment must have a representation or image of the outer environment. The structure common to adaptive systems is shown in Figure 1.

Figure 1



This structure is very similar to the problems studied by control engineers. From a control perspective, the inner environment would be labeled the controller and the outer environment, the process to be controlled.[4]

The easiest way to explain this perspective is to examine the energy policies that were discussed above. Let the inner environment be an energy office in an international organization such as the EEC, which is responsible for allocating crude oil for various refined products and setting price levels for those refined products. Let us further stipulate that the officials' goals are to maintain present community patterns and present demographic distributions of population in country members.

Information concerning the state of the environment is now represented by the vector $\underline{X}$ and might include the use of public transportation, new cars sold, and movement to and from suburban areas. The officials must have some way of observing $\underline{X}$ so that they can determine whether their goals are being acceptably met. However, they cannot observe every sales transaction or every family move directly. In fact, even if they could obtain all of this information, it would probably exceed their information-processing capability. Therefore, they need a mechanism that filters the minute information into manageable form. This is the task of the observation interface.

The observation interface is the inner environment's sensing device for gauging changes in the outer environment. In this example it might include the various agencies that collect and aggregate data on gasoline availability and price, automobile usage, automobile purchasing, etc. To avoid information overload from $\underline{X}$, the observation interface might incorporate an indicator system. Thus, instead of having a lot of information about the outer environment ($\underline{X}$) as an input, the inner environment receives $\underline{Y}$. Vector $\underline{Y}$ might include such indicators as changes in the level of public transportation use and changes in the rate of new car purchasing. In *some cases* $\underline{Y}$ *and* $\underline{X}$ *will be equivalent. Most* often, however, $\underline{Y}$ will be some summary measure of $\underline{X}$ and the notation reflects this distinction.

An important research question stemming from this perspective concerns just what information is needed to accomplish policy-makers' goals and how such information should be filtered and utilized in the policy-making process. We assume that many of the quantitative indicators or event analyses in international relations today could be used to address this particular question if goals and purposes were built into that particular research approach.[5]

Upon receiving $\underline{Y}$, the inner environment must evaluate it to determine what sort of policy is indicated. Results of this evaluation will depend on the nature of $\underline{Y}$ and on the inner environment's image of the outer environment. The image might, for example, consist of an economic model in which the critical variable is the price elasticity of gasoline for private transportation use. Generally, this image will, at least in part, contain the elements of $\underline{Y}$. In this way $\underline{Y}$ can be used to set the state of the image, and various policy alternatives $\hat{\underline{U}}$ can be put into the image *to assess the differential* impacts $\hat{\underline{Y}}$. To have any impact, the elements of the $\underline{U}$ vector must have some way of entering the outer environment; that is, the inner environment must have some access interface that can implement $\underline{U}$ in the outer environment. Refinery allocation, gasoline rationing, and price adjustments might serve as access points for the officials in this example.

Of course, the model structure outlined here merely identifies the important characteristics of adaptive systems. For theorists to implement goal-directed policy effectively in a changing environment model, the system must be capable of:

- *Specifying systems' goals in terms of* desired characteristics in the environment in which policy is implemented,

- Possessing an access interface with the outer environment which permits it to alter that outer environment,

- Maintaining a realistic mental image of that outer environment which allows it to gauge the impact of alternative policy actions prior to their actual implementation and,

- Possessing an observation interface with the outer environment which permits it to monitor changes in the outer environment constantly and *efficiently and to assess* the actual effect of the already implemented policies with respect to goals.

Assuming that the system has an identifiable set of goals and possible alternative policies, a model of the process requires an "image" of the outer environment and an observation interface for monitoring that outer environment. The goals provide criteria for utilizing policy alternatives to regulate change in the outer environment. There are three aspects of this decision process that characterize nations as systems: (1) nations are goal-seeking systems, (2) nations hold many goals simultaneously, and (3) nations are responsive to a perceived rather than an objective environment. The last of these

assertions is seen in the development of images in the above adaptive systems approach. The first, that nations are goal-seeking, stems directly from the whole adaptive systems approach and is consistent with the position held by Snyder, Bruck, and Sapin (1962), the Sprouts (1956), and Holsti, et al. (1968, 1965) on foreign policy decision-making and international relations. That nations hold many goals simultaneously is the crucial element that distinguishes them from most lower level systems. This is one of the most difficult aspects in the development of a general systems theory for large, complex systems. When dealing with nations or supernational units, social scientists must deal with the fact that there is no single goal that can adequately describe the operation of the system. If the goals of the system are inconsistent, one goal can be achieved only at the expense of the other. In that case the system (nation, organization, or individual) must determine which trade-offs are acceptable. Even if the goals are consistent, all goals may not be achieved at the same time because the systems have only a finite amount of resources. Again, the system must determine the optimum allocation of resources.

HIERARCHICAL SYSTEMS STRUCTURE

In recent years the foreign policy decision-making literature has suggested that the relationship between foreign policy decision-making responsibilities and information-collecting and distribution responsibilities is an integral aspect of effective organization performance. Edward Morse states the case succinctly: "Channeling and handling information has become an organizational problem no foreign ministry has mastered" (1970: 386). The process suggests that there are patterns of behavior that are strongly influenced by organizational position. Hillsman (1971), for instance, describes organizations in terms of the network of interpersonal relations at various levels. There seems to be a recognized agreement between policy-makers and academics on the existence of levels of authority, on the interaction of motivation and goals, and on the impact of information on preferred modes of action at different levels of the policy process. Some of the elements of these concerns can be made explicit if we introduce modern systems theories that treat organizations as multilevel systems. The concept of a multilevel hierarchy structure cannot be defined by short, succinct statements. What can be done at this point is to (1) introduce some basic concepts for classification and study of our systems in general, (2) provide a conceptual foundation for the problem of coordination, and (3) indicate some features of hierarchical systems that make them attractive for use in the study of large-scale decision systems.[6]

The total national system can be designated as a simple scheme in Figure 2, plus the ongoing process of foreign policy inputs and outputs. (See Figure 3 for a much more abstract version.)

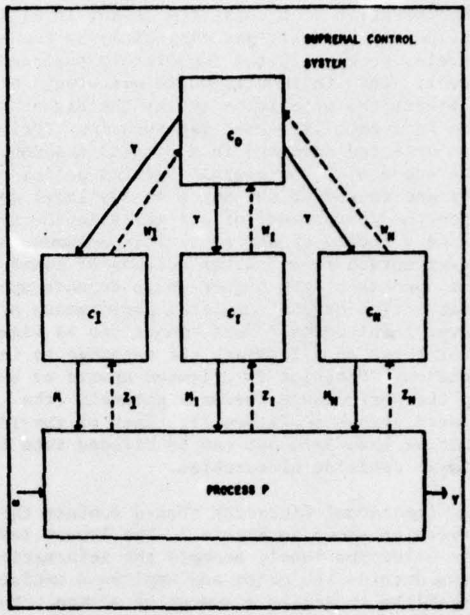


FIGURE 2 - A TWO-LEVEL SYSTEM WITH N INFIMAL CONTROL SYSTEMS AND A SINGLE SUPREMAL CONTROL SYSTEM*

* TAKEN FROM MESAROVIC, ET AL. 1971, P. 86

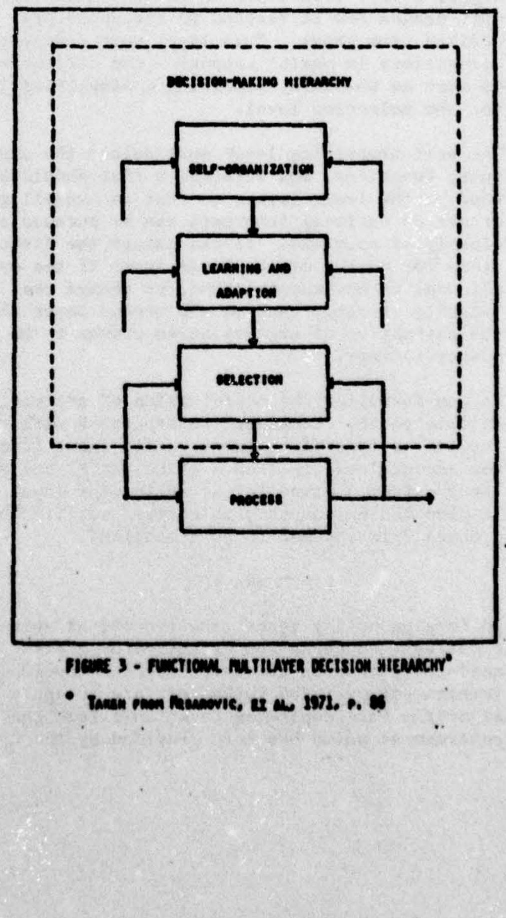


FIGURE 3 - FUNCTIONAL MULTILAYER DECISION HIERARCHY*

* TAKEN FROM MESAROVIC, ET AL. 1971, P. 86

The operation of a subsystem on any level is influenced directly and explicitly by the higher levels, especially the immediately superseding level. This influence, while not always binding, reflects the priorities set by the higher levels. The influence is termed intervention. Priorities are oriented downward in a command fashion; but the success of the overall foreign policy system and indeed of the units on any level depends upon the performance of all units in the system. Since a choice of action tacitly assumes that intervention precedes the actions of lower units, the success of the higher units depends upon that action or the resulting performance of the lower level units. Performance can be viewed, therefore, as a feedback and response to intervention. Feedback is oriented upward as shown by the performance feedback channels (the upward arrows in Figure 2). Each of the layers that we have laid out can be divided into functional decision hierarchies.

The functional hierarchy should contain three layers as shown in Figure 3. The lowest level, the selection level, accepts the information from outside the units and applies a decision algorithm to derive a course of action. The algorithm must be defined as an organizational means of reaching a solution to a specific intervention from above.

The goal of the second-layer activity, the learning and adaptation level, is to reduce uncertainty. Given a set of priorities and goals and the importance of actions from a higher level, this learning or adaptation layer must decide how to respond to the needs prescribed from above. This layer must reduce the uncertainty in making responses and initiatives as much as possible, providing a simplified job for the selection level.

The self-organizing layer must select the structure, functions, and strategies that should be used on the lower layers so that an overall goal or set of national interests can be pursued as closely as possible. It can change the directions for action of the first level if the overall goal is not accomplished, or change the learning strategy used on the second layer if the estimation of uncertainties proves to be unsatisfactory.

We can formalize the coordination of activities at this point. Consider the process P with two inputs: a control of intervention input from the second level (m from a given set M) and an input ω from a given set Ω, called the input. It also has an output y in a given set Y. The process P is assumed to be a mapping.

$$P: M \times \Omega \rightarrow Y$$

In foreign policy terms, the process or selection level concerns the execution of daily actions in each of the bureaucracies involved in foreign policy. The tasks here are to apply an algorithm for responding to stimuli from the environment which has been provided by the second level. While it is true that some policy is made in the "cables," these changes in the algorithms for responding must be in harmony with the objectives passed down from above or there may be requests for a change in activity.

The second level in our control system has two inputs: coordination γ provided by the higher level from a given set Γ, and the feedback Ξ from a given set ξ coming from the process. The output is the control intervention m selected from the set M. The system is a mapping:

$$C_1 : \Gamma \times \xi_1 \rightarrow M_1$$

At a managerial level, the task of coordinating the organizing goals of the administration with the realities of the daily routine must be carried out. It is here that decisions about the feasibility of particular plans are decided. These levels must provide policy plans for operators to use as algorithms in acting. This level must suggest plans, get them accepted by the administration, and implement them at the selection level.

The highest level is responsible for coordination. It has only one set of inputs, the feedback information w from the second level which it uses to arrive at the coordination output. The system is assumed to be a mapping.

$$C : W \rightarrow \Gamma$$

where W is the set of feedback information inputs w. Except in rare instances, such as a crisis, the administration level sets national interests, chooses a policy plan, or combines suggestions of several plans from the managerial level and assigns responsibility to a lead bureau at the second level; but it does not involve itself in the process directly.

To complete the description of this system we must specify the nature of the feedback information. The feedback information Ξ to the second level contains direct information on the process P; it is therefore a function of the control m, the disturbance ω, and the output y, given by the mapping:

$$f_1 : M \times \Omega \times Y \rightarrow \xi_1$$

Similarly, the feedback information received by the highest level contains information con-concerning the behavior of the second level and is therefore assumed to be given by a mapping:

$$f_o : \Gamma \times \xi \times M \rightarrow W,$$

which is a function of the coordination y, feedback Ξ and output m.

It should be pointed out that this functional hierarchy is based on the conceptual recognition of the essential functions in a complex decision system. It provides only a starting point for a rational approach to assign proper functions to different layers. In fact, each functional

layer can be implemented by further decomposition. For our purposes it is only essential to lay out the elements of the decision-making process and to borrow this functional hierarchy of levels or tasks so that we can demonstrate at what place a specific form of forecasting might be beneficially used. In order to do this, we need to make a set of assertions about the types of planning appropriate to each of these levels.

In spite of several common features, the tasks and roles of the system can be differentiated by levels at this point:

1. A higher level unit is concerned with the broader aspects of the overall foreign policy behavior. This is reflected in the fact that a higher level unit is superior to two or more units and its decisions determine the activities of the lower levels.

2. The decision period of a higher unit is longer than that of lower units. Lower level units are responsible for today's decisions, that is, whether to respond to previous actions or to initiate new actions. Hence, the time frame of these decisions is quite limited. However, to evaluate the effect of coordination, higher levels cannot act more often than the lower levels, whose behavior is conditioned by this coordination. Therefore, it is essential to recognize inherent differences in the time frames of most decisions as we proceed up the decision hierarchy. Certainly there are specific strategies or issues, such as the Cuban Missile Crisis, when the normal process is shortcircuited by making most decisions operative at a much higher level in the hierarchy.

3. A higher level unit is concerned with the slower aspects of the overall system's behavior whereas the lower levels are concerned with more particular local changes in the foreign policy process. The higher levels cannot respond to variations either in the environment or in the process itself which are faster than the variations of concern to the lower levels.

4. Descriptions and problems of the higher levels are less structured with more uncertainties and are more difficult to formalize quantitatively. Decision problems in the higher levels can be considered more complex and an approximation can be used to derive a solution to a higher level problem; but accuracy is then reduced. One has to be cautious when interpreting the results.

In general, for any level there is a specific set of techniques suitable for solving respective forecasting problems. According to the system characteristics, units of the higher echelons are concerned with broader aspects of the foreign policy task and therefore have a more complex decision problem than those at the lower levels. They have a longer time frame with which to look at problems, and therefore are concerned with slower aspects of the overall foreign policy behavior. As we turn to specific forecasting techniques and review their capabilities we should keep in mind these characteristics so that we can decide at which stage and at which level in foreign policy decision-making and planning the techniques are applicable.

The point that needs reemphasizing at this stage is that at each of the nodes in Figure 2, decisions must be made that result in outputs. These decisions are based upon information concerning the current state of the process and by goals either passed down in the form of interventions or decided upon at this level. But uncertainty exists at each stage and in the process of reaching decisions, forecasts of the likely impact of these decisions must be made. At certain levels responsibility for dealing with uncertainty is limited to issues with low levels of complexity. This is especially the case at the process level. In issues of higher complexity, managers or senior political officers may be brought into the decision. It is not only the case that different individuals or levels in the hierarchy are involved at different levels of uncertainty, but that different routines for handling uncertainty and information in forecasting must be employed. This brings us to the decision problem.

Three decision problems are associated with this system:

- D is the overall decision problem reflecting an exogenously given objective function, for example, a social welfare function in an economy.

- *D* is the set of N infimal decision problems reflecting the goals of each infimal participant.

- D^0 is the decision problem of the coordinators, C^0.

If we assume that D is given and known, and that certain critical characteristics of the system are known and unchangeable, such as the distribution of power and information, then we can define the active coordination problem as follows:

Definition: The active coordination problem is to find a coordination scheme, CS, implying a coordinator's decision problem, D^0, such that there exists a coordination input $g^* \in G$ with the properties that:

a. g^* solves D^0, and
b. solution of Dg^* implies the solution of D. (Here Dg^* represents the infimal decision problem *D* parameterized by g^*).

Recognizing that the subprocess interactions of C^0 give rise to the need for active coordination in a system, Mesarovic, et al. developed three modes in which interaction might be handled. These modes are called interaction decoupling, interaction prediction, and interaction estimation. Each mode is suited to classes of systems with specific distributions of power and information, a point which is relatively poorly made by the authors. Brock (1971) discusses the problem in some detail and extends the Mesarovic work by reviewing the way Aoki (1970) and Baumol and Fabian (1964) handle the issues of power and information distribution in hierarchical systems. The issues are little more than recognized at this stage in the development of formal theories in a systems perspective. But obviously if we are to adapt large, complex systems to perhaps even more complex environments we need to deal with the organizational approaches to this problem.

DYNAMIC DECISION RULES FOR COMPLEX SYSTEMS

Of the many approaches to the study of political phenomena, none has achieved more mathematical development than decision-making. It has been most frequently applied to conflict behavior (Axelrod, 1970) and strategic deterrence (Ellsberg, 1964; Hunter, 1971) in foreign policy. More specifically, previous developments have focused on decision rules which, if followed, will allegedly yield a "best" course of action (at least under the conditions specified). Unfortunately, previous rules tended either to make unrealistic simplifying assumptions or were so mathematically complex as to be less than adequate for explaining decision-making in the "real world."

The primary guide to the decision rule's formulation may be found in Chernoff who suggests the following:

> In a given problem, the statistician should first eliminate those strategies which are obviously bad. He should then dispose of some of the remaining which, while not so obviously bad, still fail to make the grade. After a certain amount of elimination, the remaining strategies will be considered adequate. The statistician will have no reason to prefer any of these strategies to the others. The set of these adequate strategies will be called the solution to the problem. It is not implied that the statistician necessarily considers that two elements of the solution are equivalent (1954: 427).

In this solution set, then (which is termed the region or class of acceptable decisions), it is not assumed that a complete and strong ordering exists among the alternatives, although that may in fact prove to be so.

The major drawback to most decision approaches is that the algorithms are static and not dynamic (Phillips and Yarnell, 1974). This assumes that the outer environment and the system's goals remain constant. Edwards notes, with respect to static approaches, that:

> In any case the decision maker chooses and executes one of his courses of action, receives the value or payoff associated with the intersection of that course of action and the state of the world which actually obtained--and then the world ends. The decision maker (in principle) never gets to make a second decision in which he might apply whatever he may have learned as a consequence of the first.
>
> In dynamic decision theory, decision makers are conceived of as making sequences of decisions. Earlier decisions, in general, produce both payoffs and information; the information may or may not be relevant to the improvement of later decisions. The objective of the decision maker may be taken to be maximization of total profit over the long-run. But it is quite likely to be desirable to give up short-run profit in order to increase long-run profit. The most common instance of such a conflict would arise in situations where some courses of action lead to more information and less profit, while others lead to less information and more profit (1962: 59-60).

Much has been written to date about decision-making in institutions (e.g., government bureaucracies), and from this research has come the notion of "bounded rationality." Hughes cites three implications of "bounded rationality":

> First, problems are generally broken up into quasi-independent parts, and the decision-makers deal with these parts individually....
>
> Second, rather than maximizing or optimizing, decision-makers will satisfice. That is, rather than considering all alternatives, and choosing one calculated to produce the most desirable consequences, organizations will select an action calculated to be "good enough." Organizations have some notion of what constitutes minimally acceptable performance, and resources devoted to decision-making beyond that level will seldom be committed. Another way of looking at this...is that there is a point beyond which the costs of greater than the expected benefits of improved action....
>
> Third, decision-makers are working in an environment of uncertainty concerning the consequences of their actions, and will act in such a way as to minimize that uncertainty. One major implication of this has been developed by Lindblom (1959). In order to obtain feedback concerning the consequences of policy, decision-makers will act incrementally and frequently, rather than attempting to completely solve a problem with initial action (1972: 19-20).

Bounded rationality, with its emphasis on feedback of performance and with its reliance on satisficing, mitigates against a static approach and moves toward a dynamic one.

A dynamic approach would probably be very difficult. Edwards suggests why:

> In dynamic situations, a new complication not found in the static situations arises. The environment in which the decision is set may be changing, either as a function of the sequence of decisions, or independently of them, or both. It is this possibility of an environment which changes while you collect information about it which makes the work of dynamic decision theory so difficult..." (1962: 60).

He goes on to suggest six different relations between the type of environment (stationary vs. non-stationary), and information about the effect of decisions on that environment. Each relation might specify a different decision rule. Edwards (1962) also presents a model of a probabilistic information processor which fits (analytically) either into the artificial system of Thorson (1973), or the hierarchic modeling of Hughes (1974), Bossel and Hughes (1973), and Mesarovic and Pestel (1972).

Let us state the problem as follows: Supposedly we are attempting to keep a system on some given path. This path may be the result of some prior optimization or it may represent some ad hoc goals such as full employment, price stability, or a target rate of growth. Further, let us assume that this path is feasible for the system. Finally, suppose that we have a choice of the following classes of policies: (1) policies based on the predictors of the role of state variables at some time in the future; (2) policies based on observations of the state variables at the present time; (3) policies that do not depend in the short run, on either estimates or observations of the state variables. Having first defined a suitable metric on the notion of stability, our problem is then to select the policy that will result in the stability for our system when (1) there are errors in the measurement of the state variables; (2) there are lags in the observation of the state variables and/or the action of the controllers, and (3) the control can be varied only in discrete amounts.

The tools with which this might be accomplished are also being developed. Obviously, the mathematics of controlling dynamic systems would be essential; here, too, Mesarovic, et al., (1970) come to mind. But it is uncertain as to how such analytic and mathematic techniques may be incorporated into a decision rule; that is, while dynamic programming and satisficing rule out linear programming and hence game theoretic spinoffs, they don't specify a unique rule as an alternative. We might propose satisficing, which as a rule says to adopt the first minimally acceptable alternative. Suppose "minimally acceptable" refers in particular to k dimensions or variables; i.e., the alternative must be minimally acceptable on all k. An alternative now comes up for evaluation. By what rule is it to be accepted or eliminated? It may be argued that satisficing says the following: If one is .X certain that this alternative will generate at least Y_i ($i = 1, 2, \ldots, k$) utility, then it is accepted; otherwise it is rejected. There are then k+1 parameters to be specified by the decision-maker.

The major advantage to this rather simple but novel representation of satisficing is that it sensitizes the decision-maker to the parameter X, a probability. This, together with the view of probability as a function of information (i.e., entropy), sensitizes the decision-maker to issues such as (1) whether to delay implementing any decision until more information is acquired in order to raise X, or at least to get a better "fix" on it; (2) when the decision-maker should stop acquiring information (Brock, 1969); and (3) the importance of having a good descriptive theory since such a theory provides information as to the more effective alternative. Finally, the explicit representation of X ought to permit more valid simulations, since obviously the range of the search over alternatives is a function of k+1 parameters: (1) the degree to which the state of the outer environment is not consistent with essential values--the k parameters--and (2) the degree of certainty with which the decision-maker views the effectiveness of the alternative--the k+1st parameter, X. Most simulations simply deal with the first k parameters and ignore X. Current work in economic development demonstrates that myopic rules can be developed which do indeed reflect the information problem present to decision-makers without reaching a level of unrecognizable mathematical manipulation (Nelson and Winter, 1973; Kelly, Williamson and Cheetham, 1974).

FOOTNOTES

1. See Miller (1973, 1972, 1971a, 1971b, 1971c, 1965). See also the Yearbook of the Society for General Systems Research. Prominent among the exponents of General Systems Theory are L. Von Bertalanfy, K. Boulding, R.W. Gerard as well as Miller.

2. Perhaps the most skeptical review of this work can be seen in Simon and Newell (1965). Simon (1969) presents a more recent review of the prospects of such a synthesis.

3. Several theorists have considered an adaptive model in the examination of social systems as particularly viable for the study of changing conditions. Among the most important are Ashby (1952); Campbell (1965); Pringle (1968); and Buckley (1967).

4. This development was first suggested by Stuart Thorson (1973). Since then both Thorson and I have applied it to the energy production problem of Middle Eastern countries, to the need to develop appropriate standard operating pro-

cedures for crisis monitoring and management (CACI, Inc., 1974c; Phillips and Thorson, 1972), and to problems of the intelligence community (CACI, Inc., 1974b).

5. See Phillips (Forthcoming 1975) for a review of events literature. For the use of quantitative indicators see CACI, Inc. (1974a). Also look at Hermann (1971); McGowan (1970); and McClelland and Hoggard (1969).

6. The development of this application of control theory stems from the work of Mesarovic, et al. (1970). For other suggestions of similar approaches see Steinbruner (1973) and Burgess (1972).

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Toward a Theory of Dimensions for
the Social Sciences*

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Abstract

Although the concept of dimension is widely used in social science research, its conceptual foundations remain unspecified. This is apparent in the lack of specificity with regard to diversity in conceptual meaning, necessary assumptions, inherent limitations and relatedness between concepts. The analysis offers a preliminary solution to this problem by identifying four concepts of dimension. Each concept may be distinguished on the basis of a rigorous logical, empirical and theoretical foundation. The foundations require that certain assumptions be met in order to utilize each concept. Given the assumptions necessary for determining each concept, certain limitations may be identified. By establishing the foundations in this analysis, it is possible to heirarchically arrange the four concepts so that each may be used in conjunction with certain kinds of research undertakings. The ultimate purpose of the analysis is to (1) establish a preliminary conceptual framework so that each concept may be fully elaborated in subsequent analyses and (2) posit a framework with which to evaluate the use of each concept in various empirical and theoretical enterprises.

Introduction

One concept which is used extensively in the social sciences is the concept of dimension. Some scholars use the concept to refer to categorization schemes for classifying the components of a phenomenon. Lazarsfeld, for example, speaks of "latent structures" which may be used to classify "manifest data."[1] And Clausen develops a theory of "policy dimensions" which may be used to understand legislative decision-making[2]. Other scholars use the concept to express some mathematical structure which may reflect relationships between important components of a phenomenon. Torgerson, for instance, uses the term to refer to an "attribute" of a particular property of a stimulus-object.[3] Anderson, et. al., in their methodology for legistlative roll call analysis suggest that dimensions are equivalent to the number of "factors" which express a given number of correlated variables in terms of a lesser number of uncorrelated ones.[4] Still other scholars use the concept to refer to the similarity among measurable aspects of a phenomenon. Rumelhart and Greeno, for example, hypothesize that the "similarity" between stimuli influences individual choice behavior.[5] Tversky and Russo use a similar concept in their study of "interstimulus similarity" and "substitutability" in binary choices among alternatives for individuals.[6]

The applications of the use of the concept of dimension illustrate its ubiquitousness in the analysis of social science phenomena, especially with regard to their variegated substantive references. The applications suggest that the generic concept of dimension masks some highly differential semantic uses of the term in ordinary language. And the applications indicate that the meaning and use of the concept may vary according to its association with logical and mathematical considerations. The very nature of the applications suggests that the concept is important in understanding social science research.

In spite of the importance of the concept of dimension, the applications are studies much more than the concept itself. This is evident in that it is possible to find many applications, but it is impossible to find a standardized conceptual analysis which will specify the alternative concepts of dimension; the assumptions, implications and shortcomings, explicit and implicit in each concept; and the relationship, if any, which exists between concepts. The concept of dimension is non-standard in its usage across social science research enterprises.

If the concept of dimension is important, yet at the same time non-standard in its usage, then there exists a need for greater conceptual clarity. With this in mind, the purpose of this paper is to (1) sort out the various concepts of dimension into categories which can be used effectively in research; (2) specify the important implicit and explicit assumptions inherent in each conceptual application; (3) offer some possible implications and shortcomings involved in the use of each concept, and (4) arrange these concepts in a useful relationship to one another so that various kinds of research problems may be undertaken.

I. The Category Concept of Dimension

The first concept of dimension which is apparent in social science research is discovered by employing a conceptual scheme whereby the components of a phenomenon are grouped, matched, pigeon-holed, isolated, analyzed, combined, consolidated or partitioned into any number of equivalence classes or categories.[7] An example of this would be the statement that a congressman's roll call vote can be understood by examining the various components: party affiliation, constituency interest, state party delegation membership, committee assignment and party leadership.[8]

Category concept of dimension defined.

Dimensions, according to the above scheme may be defined as any set of mutually exclusive categories or equivalence classes imposed upon a phenomenon

such that each element in the set represents a dimension of the phenomenon. This notion of dimension may be referred to as the "category concept of dimension."

Procedure for determining dimensions

It is important to note that no criteria of admissibility has been required or established with regard to categorizing or partitioning. Therefore, to the components of the congressman's roll call vote analysis, one could legitimately add the category of "unicorns." Perhaps this additional category shocks our sensibilities in that it is seen as not only imaginary, but also nonsensical and absurd. To entertain this view, however, is to believe strongly in the notion that somehow there exists a certain order, meaningfulness, relatedness or rationale inherent in the categories themselves. But the categorical concept of dimension only presupposes a purposiveness in an analyst's desire to classify the components of a phenomenon; it does not impose any necessary assumptions as to the relatedness of the categories themselves other than their mutual exclusiveness. In this concept of dimension, "unicorns" are admissible.

Given the above characteristics, category dimensions may serve two functions in social science research. First, thay can be used to organize the components of a phenomenon into understandable units for analysis. And second, they can serve as an initial, preparatory step in using a more restrictive concept of dimension.

II. The Geometrical Concept of Dimension

Purpose of second concept of dimension

The category concept of dimension above serves to categorize the components of a phenomenon. It avoids the use of assumptions requiring relatedness, meaning, or association between categories. In the second concept of dimension which this analysis will consider, the procedure for defining dimensions will include not only a categorical scheme, but also an attempt to specify some order, relatedness,

association, concatenation, juxtaposition, dependence, similitude (or the converse of these terms) between the categories.

Initially, then, the conceptual scheme to be developed is an attempt to eliminate as many extraneous or "non-dimensional" categories in the categorical scheme as possible by establishing a rigorous criterion which will exclude them from the analysis. This criterion will serve to eliminate categories in two ways: (1) by showing that the categories do not fulfill certain conceptual requirements and (2) by relating the categories together, thereby limiting their number or composition. By way of example, the next procedure will attempt to develop a scheme whereby "unicorns" may be eliminated from the dimensional analysis of a roll call vote, assuming that "unicorns" as a dimension would be undesirable or "non-dimensional." Of course, other categories may be eliminated in the process as well.

Foundation for a Second Concept of Dimension

In order to develop a conceptual foundation for the second concept of dimension, it is necessary to require that the concept include the principle defining characteristic of category dimensions, that is, that a phenomemon under analysis must be able to be organized into mutually exclusive categories or partitioned into equivalence classes.

Once the categorization scheme is required, a process for relating the categories or classes must be developed. Although it is possible to relate categories by any number of processes, the second concept of dimension requires that one and only one process be considered for relating categories. The process chosen for the second concept of dimension requires that a phenomemon under analysis be represented as an "arbitrary vector space."[9]

By representing a phenomenon as an arbitrary vector space, it becomes possible to express the categories or equivalence classes of a phenomenon in terms of scalars and vectors. The representation of categories as vectors

suggests two possibilities. The first may be labeled as a linearly dependent vector, or dependent vector. It may be defined as: given V, an arbitrary vector space, and K, a field of scalars, a set of vectors $v_1,\ldots,v_n \epsilon V$ are linearly dependent over K, if there exists scalars $a_1,\ldots,a_n \epsilon K$ not all of them 0, such that: $a_1v_1 + a_2v_2 + \ldots + a_nv_n = 0$. The second may be labeled as a linearly independent vector, or independent vector. It differs from the dependent vector in that: $a_1v_1 + a_2v_2 + \ldots a_nv_n = 0$, if and only if $a_1 = 0$, $a_2 = 0,\ldots,$ $a_n = 0$.

Geometrical Concept of Dimension Defined

With the above concepts in mind, the second concept of dimension may be defined as: if the vectors $v_1, v_2,\ldots,v_n$ are linearly independent such that every vector in V can be represented by these n vectors, then these vectors form a basis for V, the arbitrary vector space, and the "dimension" of V is n. This may be symbolized as dim V=n. Another concept which is identical to this is the concept of dimensionality. When a social science phenomenon is given as above, the "geometrical concept of dimension" is being used.

Some Procedures for Relating Dimensions

By using the geometrical concept of dimension, it is possible to reduce the number of categories which might serve as dimensions. First, the categories are greatly reduced in number when an analyst requires that they be utilized only when representable as vectors in a vector space. Once the set of vectors is chosen for analysis, the dependent vectors may be eliminated as possible dimensions since they may be expressed as a combination of independent vectors which are in fact dimensions. In using geometrical dimensions, an analyst is not forced to accept any basis, but is free to manipulate or transform vectors in an analysis to construct any number of different bases. This suggests that vectors derived in an analysis may be treated as dependent in one model and

independent in another.

In order to relate dimensions together, an analyst may perform many different operations upon the vectors in a given vector space. Among these would be scalar multiplication, vector addition and inner product.[10]

Geometrical Dimensions: Some Assumptions and Implications

Having represented a phenomenon under analysis with an arbitrary vector space and having defined dimensions as independent vectors in the arbitrary vector space, an important question occurs with regard to the justification or rationale for such a conceptual scheme. There appears to be at least three reasons which are identifiable. First, the phenomenon may be represented as a vector space model merely by assuming that such a representation makes sense for the sake of analysis. Second, several previous analyses of the phenomenon or similar phenomena may suggest the representation. Or third, an entirely different method of analysis of the phenomenon may suggest the representation. Although these reasons are entirely different in a procedural sense, all three have in common the notion that the phenomenon must be "stipulated" as equivalent to a representation as an arbitrary vector space.

Once the rationale for the use of the geometrical concept of dimension is established, the vector space model of the phenomenon suggests several important implications. First, since dimensions in an arbitrary vector space are equivalent to independent vectors defining the basis of the vector space, it makes no sense to speak of partial or incomplete dimensions in a vector space. Dimensions either exist in this sense or they do not. This is given as an all or nothing proposition.

Second, if during the course of an analysis any portion of the vector space criterion is violated, then the use of the geometrical concept of dimension is curtailed. Violation of the criterion may occur in many forms. One way would be a case wherein an analyst becomes unwilling to accept a theorem

derived from the axioms comprising the vector space model. When this situation occurs, an analyst must either abandon the model or reconstruct the model; but the analyst may not ignore valid theorems and still use the geometrical concept of dimension. And another way which is similar to that above would involve the use of mathematical operations such as vector addition and scalar multiplication. Should a situation arise wherein certain mathematical operations become unacceptable, then the vector space model in use must be abandoned or reconstructed, but the results of valid operations must always be accepted once a model is formulated.

And third, the geometrical concept of dimension may be given as a proper subset of the category concept of dimension. Therefore, what is true for the category concept of dimension is also true for the geometrical; but, what is true for the geometrical may not be true of category dimensions.

Formal and Empirical Relational Structures Distinguished

The geometrical concept of dimension as presented requires that any phenomenon under analysis be representable as an arbitrary vector space. An important consequence of this is that empirically diverse phenomena may have the same underlying mathematical structure: the same vector space model may represent a roll call vote, general equilibrium in an economy, and the motion of particles suspended in a liquid. An example of an underlying logical relation in a mathematical structure common to all three phenomena might be the relation "greater than," symbolized ">". The logical relation "<" can be analyzed and manipulated independently of whether one is working with votes, equilibria or particles. When it is possible to speak meaningfully about the underlying mathematical structure without reference to the empirical nature of the phenomenon, then the discussion concerns a "formal relational structure."[11] In addition to manifesting a formal relational structure, an arbitrary vector space may be used to represent an "empirical relational structure," which may be illustrated

by the following: Suppose an analyst observes two phenomena. One concerns a relationship between attitudes, while the other concerns a relationship between physical measurements of length. Now, it is clear that both phenomena may be stipulated to have common logical relations in the same formal relational structure. For example, it may be the case that some component x is "greater than" some component y in each phenomenon represented. When the phenomena are examined with regard to their empirical relational structure, however, the simple formal relation becomes greatly modified by the inclusion of empirical components in the relations. Taking the same phenomena, an attitude x becomes more "intense" than another attitude y, and a length x becomes "longer" than another length y. Clearly, there is an important difference between "intensity" and "length," even though the formal relation "greater than" is the same for both phenomena.

Geometrical Dimensions: An Important Limitation

In order to adequately account for empirical relations such as "intensity" and "length" above, it is necessary to develop an explicit, well-formulated theory of measurement. A theory of measurement as a minimum requires a specification of (1) a deductive system consisting of a complete set of axioms and transformation rules to be used in an analysis, (2) a model-theoretic or semantic interpretation of the deductive system in terms of empirical relations, (3) a means for partitioning actual operational definitions and measurement operations into equivalence classes, and (4) a procedure for relating the results of points 1-3 above in a logically consistent manner across a wide range of empirical and theoretical applications.

Requiring a theory of measurement to account for empirical relations as above would greatly reduce the possibilities for analysis in the social sciences, since the level of knowledge in many practical applications is not sufficiently developed to fulfill the requirements of a well-formulated theory of measure-

ment. At the same time, it is desirable in the pursuit of knowledge in the social sciences to attempt to attain as much rigor as possible in dealing with empirical relations, even though certain limitations may exist. This being the case, the geometrical concept of dimension may be seen as dealing primarily with the problem of representing formal relations in arbitrary vector spaces; while the representation of empirical relations is only required to the extent that it is practicable in the particular application under analysis.

The Usefulness of the Concept

Given the above conceptual scheme, geometrical dimensions serve three functions in social science research. First, they allow for a specification of dimensions in rigorous mathematical terms, that is, independent vectors in an arbitrary vector space. Second, they allow for these dimensions to be meaningfully related to one another through such operations as vector addition, dot product and so on. And third, they serve as preparatory step in developing a third concept of dimension which will adequately account for a well-formulated theory of measurement.

III. Dimensions as Concepts of Measurement

Purpose of the Third Concept of Dimension

In the third concept of dimension, an attempt is made to discover a conceptual scheme which will not only account for formal relations as does the geometrical concept of dimension; but also will account for empirical relations. The process for specifying such a conceptual scheme involves finding a means for (1) determining relevant and irrelevant dimensions, (2) determining the completeness of the set of dimensions relevant to a phenomenon, (3) defining a functional relationship between dimensions, (4) specifying the nature and importance of dimensional constants and (5) dealing with

the concept of similarity which becomes important when moving from the phenomenon as a prototype to the phenomenon as a model. In so doing, "intensity" and "length" become important in determining, distinguishing and relating concepts of dimension.

Foundation for a Third Concept of Dimension

The foundation for a third concept of dimension, based upon an empirical relational structure involves three equally important theoretical concerns. First, the concept of dimension must be compatable with a theory of measurement[12] that allows for (1) the specification and in principle performance of actual operational or measurement procedures upon a phenomenon, and (2) the assignment of an interpretation of meaning to a purely deductive system or formal language. Such a theory of measurement is based upon the interpretation of the concepts: quantity, scale, unit, magnitude, and fundamental and derived measurement.

Second, the concept of dimension must be based upon a specific deductive system or formal language.[13] One such system or language would be first order logic or first order predicate calculus. The deductive system or formal language is important to the concept of dimension in that it constitutes an axiom set which represents (1) the primitive statements or proper axioms used to determine dimensions and (2) the set of rules or calculus axioms used to manipulate dimensions. An axiom set of this kind may be referred to as a "theory" in mathematical logic.

And third, the concept of dimension must be an integral part of a "model" for the deductive system or formal language "interpreted" in light of the meaning (semantics) given in the theory of measurement. A mathematical model for a theory which is realized by the given formal language and theory of measurement may be referred to as a "quantity structure."[14] A quantity structure may be thought of as one kind of empirical relational structure.

Measurement Theory

One objective of any science is to measure phenomena. Since not all phenomena are measureable, science is limited to measurement of a certain class of phenomena. This class of phenomena will be designated as a set of "quantities." More formally, a quantity is an entity capable of being assigned a numerical value either as a variable or a constant. Two examples of quantity would be time and distance.

In order to determine or designate a quantity, two conditions are necessary. First, there must exist a "rule" for defining the measurement of a quantity. Call this rule a "scale" and let it satisfy the following criteria:[15] (1) makes numerical assignments across every aspect of a quantity and not just a portion of it, (2) the same numerals are always assigned under the same conditions, and (3) there exists the possibility of assigning different numbers to different quantities, or to the same quantities under different conditions. And second, there must exist a "unit" name which specifies precisely the particular scale on which the numerical assignment is made to a given quantity.[16] Examples of units would be seconds and meters.

Units of measurement, for purposes of this analysis, are of two kinds: "fundamental" and "derived".[17] The fundamental units of measurement are those which do not depend upon the measurement of anything else. In physics, for example, the fundamental units are based upon the quantities time, length and mass. The derived units are those which do depend upon the measurement of something else. For the most part derived units may be determined or developed by combining two or more fundamental units. For example, the derived unit "cubic inches" results from the cubing of a quantity length in inches.

One important characteristic of fundamental and derived units is that their initial desigation is quite arbitrary. In one system of measurement a unit may be fundamental, while in another it may be derived. A practical

example in physics is that the quantity "force" may be fundamental in one system, given as f, but derived in another, where force is equal to mass times acceleration ($f = ma$). Once the fundamental units are determined, however, the derived units may be expressed only as combinations of fundamentals. The only real restriction upon the use of fundamental and derived units is that they be used in a logically consistent manner.

Having determined or designated a quantity in terms of scale and unit, the quantity may be measured in fact or treated as being measurable in principle. The quantity being measured, when associated or compared with a unit of measurement may be said to possess "magnitude."[18] More specifically, magnitude is defined as a ratio of a quantity to a unit of measurement. For example, the length of a table is two feet. A magnitude then, may be thought of as an expression or representation of a quantity.

The expression of a quantity as a magnitude must be qualified in one important way,[19] perhaps best illustrated by an example. Suppose a quantity representing a congressman's attitude on welfare policy is measured as a series of responses on an interview questionnaire. Next, suppose that the attitude is measured as a function of some physiological reaction in the congressman's cognitive process. Clearly, both define an "attitude" on welfare policy, yet neither may be converted into the other. In other words, the expression of the quantity as a response cannot be mathematically transformed into the expression of the quantity as a physiological reaction. When this situation occurs, the scales of measurement relating to a magnitude must be referred to as "dissimilar." If the expressions of the quantity could be converted one to another, then the scales must be referred to as "similar." An example of a set of similar scales would be inches, feet, yards and meters.

Even though a quantity is measured by means of a scale and unit, expressed as a magnitude and determined by fundamental or derived units; nothing can

be said about the "actual" or "real" nature of quantities. It is not known whether they are metaphysical, theoretical, logical, empirical or quasi-empirical entities, or, simply nonsensical or meaningless. Therefore, in this theory of measurement, statements about quantities are not to be treated as statements about quantities themselves, but instead are to be treated as statements about scales, units and magnitudes which are expressions or representations of quantities.

The Quantity Structure

In Part II, the analysis suggested that an arbitrary vector space constituted a model for a theory from which the geometrical concept of dimension could be constructed. Dimensions in this conceptual scheme were defined as independent vectors in a vector space. Empirical relations were discussed under the geometrical concept of dimension, but a well-formulated theory of measurement which would account for them was not imposed upon the model.

It is possible to account for empirical relations and measurement theory in an arbitrary vector space model by restricting the "interpretation" and "realization" of theory so that quantities and their accompanying conceptual framework are included in the semantics of the model. This means that dimensions of a vector space no longer refer to independent vectors in the space, but instead refer to quantities. Of course, quantities are still expressed in the same way as vectors. When the vector space model includes the restrictions imposed by the notion of quantity, the analysis will refer to the model as a "quantity structure."[20]

Dimension as a Concept of Measurement Defined

It was suggested that units name particular scales of measurement. And it was also suggested that although the units of measurement may be different when comparing several scales with one another, some of these scales may in

fact be viewed as "dissimilar." By combining these notions with the concept of dimension as relating to quantities in a quantity structure, dimension may be defined as a particular class of similar scales used in the measurement of a quantity and expressible as independent vectors in a quantity structure.[21] When this concept is being used, dimensions are considered as "concepts of measurement."

In order to symbolically distinguish quantity structures and dimensions from vector spaces and their dimensions, quantity structures are given as bracketed capital letters, [A], and dimensions are given as bracketed lower case letters, [a].

Four Important Properties of Quantities in a Quantity Structure

When the theory of measurement is combined with a quantity structure to form a model, the following properties are appropriate to the analysis of a quantities: (1) quantities are to be measured on a ratio scale, regardless of whether this is stated explicitly or implicitly in an analysis; (2) quantities may be combined multiplicatively; (3) quantities may be combined by division; and (4) it is possible to extract integral roots of positive quantities (for example, $25m^2$ equals $5m \times 5m$).[22]

Quantity Structures and Dimensional Analysis

Having defined quantity structures and dimensions, and having given an account of measurement theory, the analysis will next consider some important restrictions and properties relating to quantity and dimension.[23]

Dimensional Equations and Numerical Laws

Once the concept of dimension is defined and the rules for manipulation of the concept are specified, the notion of "dimensional equation" may be developed. A dimensional equation is an equation which defines a relationship between two or more quantities expressed as magnitudes. Dimensional equations

are of two kinds, "definitional" and "empirical."[24] A definitional equation expresses relationships between dimensions of quantities which are true by definition. An empirical equation expresses a proposed relationship between dimensions which are true as a result of an empirical investigation.

Definitional dimensional equations in and of themselves may be "vacuously true" in that they are mathematically true, but are not brought to bare in any empirical way. Empirical equations in and of themselves may be erroneous, since they are potentially at least formally invalid. Clearly, the combination of the definitional and empirical, defined over the quantity structure, provides the most powerful explanatory procedure; since it limits the occurrence of these extraneous statements in an analysis. Of course, it must be noted that what is extraneous in one analysis may not be so in another.

The combination of definitional and empirical equations still allows for many extraneous statements. One way to further limit their occurrence is to require that dimensional equations express only "functional relationships" between dimensions. These functional relationships which limit dimensional equations may be defined as "numerical laws."[25] The most general form of a numerical law may be symbolized as $y = f(x_1, x_2, \ldots, x_n)$, where y is a derived measurement expressed as a function of a combination of derived and/or fundamental measurement given as $x_1, x_2, \ldots, x_n$.

By requiring that dimensional equations be limited to numerical laws, an empirical relation might be represented by the following. First, a quantity may be expressed in terms of magnitudes which represent the results of actual or in principle measurement operations. This is apparent in the necessary use of fundamental measurement operations expressed as classes of similar scales. And second, a quantity may be represented as a functional relationship between magnitudes which also depend upon measurement operations. This is apparent in that many functional relationships are discovered by

empirical testing and simply by formal/deductive manipulation. Both points illustrate the possibility of including extensive empirical considerations in what would otherwise be purely formal relation with empirical labels.

Dimensional Homogeneity

Dimensional analysis requires and defines an important property of all numerical laws: the "principle of dimensional homogeneity."[26] Briefly, the principle involves the notion that when every magnitude occurring in a numerical law is reduced to its fundamental units of measurement, every term in the equation consists of the same magnitudes raised to the same power. Stated in a slightly different way, the exponent of a dimension of a quantity in any term of a numerical law must be the same as that in any other.

The principle of dimensional homogeneity provides the basis for the notion that the form of the numerical law does not in any way depend upon the choice of fundamental units of measurement in a quantity structure. An example[27] of this may be given as follows: suppose an initial measurement in a consistent system of measurement yields the numerical law $y = f(x_1, x_2, \ldots, x_n)$. Next, suppose that the units of measurement are changed, yielding the numerical law, $\bar{y} = f(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n)$. If the numerical laws are homogeneous, then the same functional relationships are maintained in the equations even though the units of x_i are changed to $\bar{x}_i$. This suggests that the quantities have a definite relationship with one another independent of the units which may define the measurements upon them. This definite relationship is sometimes referred to as the "absolute significance"[28] of relationships between quantities. At any rate, the relationship is equivalent to a mathematical function which maps the structure [A] onto itself (i.e., $f:[A]\to[A]$) so that the function is one-to-one and onto.

When the numerical laws are dimensionally homogeneous, dimensional analysis can deal with the problem of relevancy of dimensions with regard

to accounting for empirical relations.

To begin with, dimensional analysis can separate the relevant and irrelevant dimensions.[29] Once this is accomplished, the relevant dimensions are retained, while the irrelevant are dropped from the analysis. If the remaining relevant dimensions are complete, that is, if all of the necessary dimensions are given or determined, then dimensional analysis is finished. At the same time, the problem of relevancy is solved. Returning to the example of a congressman's vote, the procedure would eliminate "unicorns" or any other irrelevant dimensions. Note the geometrical concept of dimension eliminated "unicorns" from the basis exclusively by stipulation.

If the set of relevant dimensions is incomplete, dimensional analysis cannot determine what they are. In addition, the analysis cannot indicate what they might be. Therefore, additional empirical or theoretical analysis would be required. Even though this may be the case, it is possible to obtain a partial solution from an incomplete set of relevant dimensions.

<u>Dimensional Constants</u>

Just as the principle of dimensional homogeneity restricts the mapping procedure undertaken in a dimensional equation, dimensional constants may also serve to restrict or at least modify these equations.[30] A "dimensional constant" may be defined as a constant of proportionality between two or more quantities expressed as magnitudes. Several well-known dimensional constants in physics are: universal gravitational constant, velocity of light and electron charge.

The importance of the dimensional constant in accounting for empirical relations cannot be over-stressed. Perhaps a simple example from physics will illustrate this point. Suppose an analyst wishes to discover the gravitational attraction between two objects. All of the important quantities and dimensions are given as:

Quantity	Dimension
mass of first body	m_1
mass of second body	m_2
distance between bodies	r
time of revolution	t

The most general form of the dimensional equation would be $t = f(m_1, m_2, r)$. On the left side of the equation one finds a unit of time, but on the right no such unit is given. Clearly, some expression is missing from the equation which will make the functional relationship true. In this case, the missing element is the universal gravitational constant G, given as $m^{-1}l^3t^{-2}$. The appropriate dimensional equation becomes $t = Gm_1m_2/r^2$.

The inclusion of the constant in the equation is important in the following ways. First, the dimensional constant significantly alters the original equation. Second, the constant exists independently of the quantities being analyzed in the analysis. Third, the constant cannot be derived from any combination or manipulation of the given quantities. Fourth, it cannot be discovered a priori, but depends upon the results of related empirical analyses. And fifth, the constant is necessary in order to arrive at an appropriate solution for the equation, or more generally to express a numerical law.

Dimensional analysis, based upon dimensions as concepts of measurement can account for the modifications resulting from the requirement of dimensional constants in some dimensional equations. The possibility of including dimensional constants which are in part empirical adds further reason for believing that empirical relations may be accounted for under this concept of dimension.

Principle of Similitude

Above, the principle of dimensional homogeneity was shown to restrict functions in quantity structures so that a mapping $f: A \to A$ remained the same

regardless of the units used. Sometimes it may be necessary or desirable to perform a different kind of mapping which would take some structure [A] onto another structure [B] using various kinds of transformation operations. For example, it might be useful to build a model[31] airplane, test it in a laboratory, and then by applying various transformation operations attempt to build a full-scale airplane prototype.

As before, the structure of the model and the prototype upon which transformational operations are to be performed are of two types. The first is the formal relational structure which involves the logical properties of the representation of a phenomenon. The operations which are appropriate to this structure are those appropriate to any arbitrary vector space. And further, all results of appropriate operations must be accepted in order to use the arbitrary vector space model. The second is the empirical relational structure which involves some logical properties and some empirical ones. All appropriate operations and the results of these operations which apply to the formal structure may not be acceptable when performed on the empirical relational structure. When they are appropriate to the empirical structure, the "principle of similitude"[32] is being utilized. The principle may be stated as follows: there exists the possibility that the primary and secondary quantities of a quantity structure are such that an equivalent quantity structure may be constructed which are exactly similar to the initial expression. of the quantity structure.

The airplane example above provides a means whereby the different between transformation operations in the formal relational structure and those in the empirical relational structure may be illustrated. Suppose that an aerodynamic engineer constructs a model airplane and tests it in his laboratory. The model performs as predicted. Next, the engineer constructs a full-scale prototype of the model. A test pilot flys the prototype airplane and it

crashes. A subsequent analysis of the environmental factors shows that this was not the cause of the crash. The prototype as a scaled transformation of the model remains as the only possible source of trouble. One explanation for the crash is that the model and prototype differ according to some "scale factor influence."[33] This refers to the fact that even though transformations on a formal structure may be valid, there may be additional modifications which are empirically necessitated, but which are not indicated by any of the formal requirements. In the airplane example, the engineer may modify the prototype by incorporating changes which are necessitated merely as a function of moving from one size model to another.[34]

Dimensions as concepts of measurement can account for the problems relating to the principle of similitude, either by requiring that operations upon empirical relational structures maintain a certain similitude or by showing that similitude is not a *problem in performing* a particular operation or a particular empirical structure.

Relationship Between Geometrical and Measurement Dimensions

The quantity structure with its explicit notion of dimension gives use to additional rigor and restriction with regard to the arbitrary vector space model given in the geometrical interpretation of dimension. This is accomplished primarily by means of the inclusion of measurement theory in a model-theoretic quantity structure. This suggests, therefore, that dimensions as concepts of measurement might be viewed as a proper subset of the geometrical concept of dimension.

A Potential Problem

The methodological underpinning of dimensions as concepts of measurement consists of a concatenation of the empirical, theoretical and formal in such a way that each is important in developing a theory of dimension. In addition,

each must be weighed against the other so that scientific explanation becomes in many ways a synthesis of these components. The clearest instance of this occurs when transformations from models to prototypes are undertaken. The theoretical and formal aspects of the model and prototype suggest that the results of a transformation may be valid; but a comparison of these results with the empirical results of measurement operations suggests that these transformations must be modified by adding in "scale factor" influence in order to match the theoretical/formal solution with the empirical solution.

These modifications (transformations having only one case) usually are not thought of as anomalies, but instead appear to be the result of measurement error or incomplete information about the nature of this problem under analysis. One question arises from this: are these modifications the result of imprecision and insufficient information, or could they represent an incorrect conceptualization of the concept of dimension? In other words, is there a fourth concept of dimension which could eliminate these anomalies?

Unfortunately, the method cannot answer these questions within its own conceptual framework. To illustrate this it is only necessary to review the method in a cursory way. First, certain theoretical, formal and empirical considerations are formulated in order to construct a quantity structure which is stipulated as representing a phenomenon. Next, some components of the quantity structure are operationally defined, either in fact or in principle. Then, measurements are performed and results are obtained. And, the results are compared with the initial theoretical, formal and empirical considerations. These results either support the initial considerations or are used to modify them. Once this process is completed it begins over again <u>ad infinitum</u>.

These representations are essentially arbitrary and are limited only in terms of logical consistency, validity, applicability and convenience. There-

fore, if an anomaly in one representation is to be understood or eliminated, then it is necessary to construct another representation. One problem with this is that the representations can only be evaluated in terms "relative" to one another. They cannot be evaluated in terms which are "absolute." Clearly, this is a function of the arbitrariness of the method. It is apparent then, that there exists no means whereby one can transcend the method itself in order to evaluate any representation.

The problem of anomaly as presented above seems to offer two alternatives. The first would suggest that the problem is in fact a shortcoming or limitation in the use of dimensions as concepts of measurement; but that the effects of the problem can be ameliorated or understood in most cases so that the problem may not be as severe as it first appears. At any rate, even if the problem was severe, there is no way to solve it. The second would argue that the problem is in fact severe in cases where it is known to exist, but even more important, there exists a possibility that its ultimate effects may go unnoticed thereby undermining the entire approach. The solution to the problem of anomaly for this alternative seems to lie in the examination of the "absolute" nature of the phenomenon and not its "representation" relative to something else.

In one sense, the third concept of dimension may serve as a preparatory step in developing the criteria for a fourth concept of dimension.[35] In another, depending upon the possibility of developing the fourth concept of dimension, it may serve as a final or ultimate concept of dimension.[36]

IV. The Absolute Concept of Dimension

Purpose of the Fourth Concept of Dimension

Dimensions as concepts of measurement allow for an adequate treatment of empirical relations by constructing models which are quantity structures. One

problem arises when using this concept, however, and this involves the possibility that a phenomenon may be represented by stipulating an infinite number of quantity structures. The problem with this is that certain anomalies may arise when comparing or moving from one structure to another. The problem may be one of measurement imprecision on the one hand, or insufficient knowledge on the other.

In the fourth concept of dimension, analysts may accept measurement imprecision and insufficient knowledge as courses of anomaly, but they suggest that these may also be caused by the "arbitrariness" and "relativity" in presenting quantity structures for analysis. Therefore, the purpose of the fourth concept is to eliminate arbitrariness and relativity, and substitute in instead, a notion of some "absolute" representation of a phenomenon.

Foundation for a Fourth Concept of Dimension

In the development of the empirical, formal and theoretical foundations of the categorical, geometrical and measurement concepts of dimension, it was possible to specify precisely the nature, assumptions and limitations of each. Unfortunately, no such precision exists with regard to a specification of the foundation of a fourth concept of dimension. For the most part, mention of the concept has been either limited to mere allusion suggesting that the concept is the next logical step to be taken after the development of dimensions as concepts of measurement;[37] or, mention has been in the form of a categorical rejection of the concept.[38] At any rate, little or nothing has been forthcoming concerning the precise nature of the concept or even its possibility.

A General Sketch of the Concept

Since there is no information concerning the foundations for a fourth concept of dimension, on a superficial treatment of some possible characteristics of the concept may be given. Of course, it will be impossible to state how this

foundation may be achieved or even if such a foundation is possible. The following constitutes a catalog of some important considerations.

1. A theory of measurement might be developed which would not be based upon operational definitions and measurement operations, but instead upon some actual, knowable characteristic of the phenomenon itself. If this were not possible, then a weaker version of this measurement theory would require that only one operational definition or set of operational definitions actually characterizes a phenomenon, while the others would be rejected as meaningless or nonsensical in absolute terms.

2. An axiom set would be necessitated such that every axiom accounted for or characterized every component and relation of a phenomenon derived from the theory of measurement.

3. A model which would "realize" both the theory of measurement and formal theory aspects of a phenomenon would require specification. The model would then constitute a homomorphism with the knowable properties of the phenomenon itself.

4. Quantities, scales, units, magnitudes and dimensions would be unique and invariant with respect to a given phenomenon. Similarily transformations between units, scales and magnitudes would then be eliminated.

5. The quantities, scales, units, magnitudes and dimensions of a phenomenon would be combined to form dimensional equations and numerical laws according to one and only one functional relationship which is unique and invariant.

6. Dimensional homogeneity would characterize each valid dimensional equation.

7. Dimensional constants would be eliminated in the sense of not being discovered in another separate empirical analysis. Instead, dimensional constants would be unique and invariant in each dimensional equation characterizing a phenomenon.

8. The principle of similitude would apply, but there would exist no ameliorating or modifying effect due to scale factor influence.

A concept of dimension which manifests at least the eight criteria above may be referred to as the "absolute concept of dimension."

<u>Some Strategic Considerations in Searching for Absolute Dimensions</u>

One group of scholars argue that the absolute concept of dimension does not or could not exist. Therefore, it is meaningless, as well as costly to attempt to develop such a framework. Another group argues that absolute dimensions have not been found simply because the proper questions in the proper framework have not been asked, so that an effort in this direction would be of great value. The proponents of the former argument cannot legitimately reject absolute dimensions outright since they cannot transcend the relativity considerations inherent in the fabric of their own method. The adherents of the latter position, having proposed no method for defining and discovering absolute dimensions, cannot show that there are grounds for accepting the existence of absolute dimensions.

The solution to this impass seems quite simple. To begin with, it is hard to see why the development of absolute dimensions, if they do exist, would not arise out of some crisis in scientific explanation which dimensions as concepts of measurement could not account for. This being the case, both groups should be able to participate in any ongoing scientific paradigm, although their individual purposes in some ultimate sense would be quite different.[39] In this way, no additional costs are accrued and no a priori acceptance or rejection of the concept is entertained. Research would continue in spite of the lack of resolution of this theoretical problem.

V. Conclusion

The analysis above identified four related concepts of dimension which may be of use in the social sciences. The first of these was discovered by classifying the various components of a phenomenon. Dimensions derived from this procedure are referred to as "category dimensions" so that each classification constitutes a single or separate dimension.

Once category dimensions are determined, a second concept of dimension may be developed. This involved a conceptual scheme such that a phenomenon is treated "as if" it were an abstract vector space with its components given as either dependent or independent vectors. This is based entirely upon the willingness of an analyst to "stipulate" the equivalence of a phenomenon and a vector space. Dimensions found by this procedure are referred to as "geometrical" concepts of dimension, and are equivalent to independent vectors in the arbitrary vector space. The advantage of this method over the categorical is that the procedure allows for the specification of the "relationships" between dimensions in mathematical terms.

Building upon the geometrical concept of dimension, it is possible to determine a third conceptual scheme whereby dimensions are not only categorized and formally related, but also allow for a representation of empirical relations in a model. The procedure which determines this conceptual scheme is based upon a "realization" of a theory of measurement and an arbitrary vector space as a mathematical model given as a "quantity structure." Dimensions found in this method refer to classes of similar scales, which represent independent vectors in a quantity structure. Dimensions are characteristic of quantities and based upon operational definitions or measurements performed.

It is not clear whether measurement dimensions can be restricted further to construct a fourth concept of dimension. But, assuming that one can or

that this should at least be attempted, the fourth concept of dimension would allow for a transcendence of the dimensions which relate exclusively to sets of operations, and attempt instead to apply the concept of dimension directly to an absolute representation of the phenomenon itself. The purpose of the procedure would be to eliminate relativity arising out of a combination of measurement theory and model theory. If this method were possible, dimensions of a phenomenon would be "absolute."

The four concepts of dimension are arranged so that the absolute is a proper subset of the measurement, the measurement of the geometrical and the geometrical a proper subset of the categorical. This may be illustrated in the following Venn diagram.

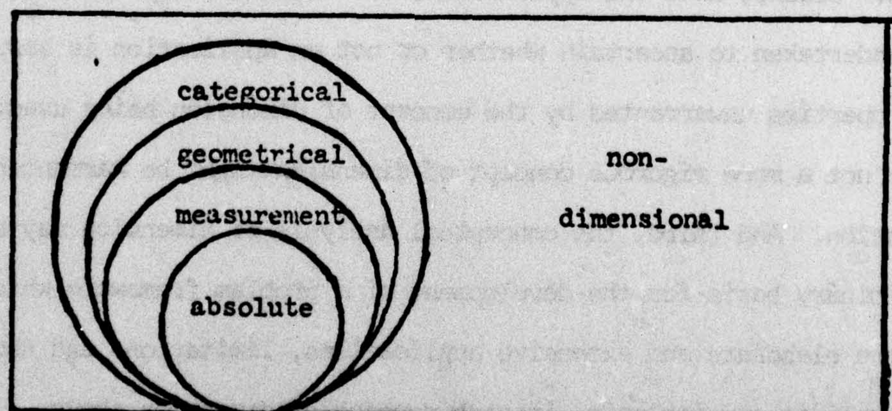

Figure 1

The advantage of arranging the concepts in this manner is that the results of an analysis based on one concept can be used as a preparatory or initial step in an analysis using a subsequent concept of dimension.

The above classification scheme for dimensions is not intended as a "cookbook" procedure for specifying how one would go about discovering dimensions in a social science research enterprise. Instead, it is a conceptual analysis which relates a rigorous framework for determining whether or not a concept of dimension is being used, and if so which one. In order to accomplish this, each concept is catalogued according to its assumptions, relationships, implications and limitations all of which indicate what one should mean when using any concept of dimension.

Once the above conceptual framework is established, it should be possible to accomplish in subsequent analyses three additional undertakings: first, various research enterprises both empirical and analytical may be analyzed in terms of the four concepts of dimension to see how the concept is applied. Second, once the applications are examined, additional analyses might be undertaken to ascertain whether or not an application is assumed to have properties unwarranted by the concept of dimension being used; or whether or not a more rigorous concept of dimension might be warranted in an application. And third, the conceptual analysis of dimension may serve as a preliminary basis for the development of a problem framework which would suggest more elaborate and extensive applications, limitations and shortcomings, explicit and implicit, in each concept of dimension above.

FOOTNOTES

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2. Clausen, A. R., How Congressmen Decide: A Policy Focus, (New York: St. Martin's Press, 1973), Chapter 3.
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4. Anderson, L. F., et. al., Legislative Roll-Call Analysis, (Evanston: Northwestern University Press, 1966), Chapter 7.
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8. See C. H. Cherryholmes and M. J. Shapiro, Representatives and Roll Calls, (Indianapolis: Bobbs-Merrill, 1969) for a review of the literature in this field.
9. For a complete presentation of this concept see S. Lipschutz, Linear Algebra, (New York: McGraw-Hill Book Company, 1968) Chapter 4 and L. Leithold, The Calculus with Analytic Geometry, 2nd ed., (New York: Harper and Row, 1972) Chapter 15.
10. See references in footnote 9 for most of the important axioms, theorems and operations concerning arbitrary vector spaces.

11. See J. Coleman, "The Mathematical Study of Small Groups," in H. Solomon, ed., Mathematical Thinking in the Measurement of Behavior, (Glencoe: Free Press, 1960), pps 19-22 and 31-34 and C. Coombs, et. al., Mathematical Psychology, (Englewood: Prentice-Hall, 1970) pps 10-14.

12. See N. R. Campbell, Physics: The Elements (Cambridge: Cambridge University Press, 1920); B. Ellis, Basic Concepts of Measurement,(Cambridge: Cambridge University Press, 1968); and P. W. Bridgman, Dimensional Analysis, (New Haven: Yale University Press, 1922); and J. Pfanzagl, Theory of Measurement, (New York: Wiley and Sons, 1968), for an extensive treatment of measurement theory.

13. This step is quite important, yet at the same time is highly complex and lengthly to explicate so a detailed examination was omitted. Several clear examples of the procedure may be found in the following: A. Tarski, Introduction to Logic and the Methodology of the Deductive Sciences, (New York: Oxford University Press, 1965) pps. 120-130; G. Hunter, Metalogic: An Introduction to the Metatheory of Standard First Order Logic (Berkeley: University of California Press, 1973), Part III; and W. Hatcher, Foundations of Mathematics; (Philadelphia: W. B. Saunders, 1968) pps. 36-44.

14. See S. Drobot, "On the Foundations of Dimensional Analysis," Studia Mathematica, 14 (1953) pps. 84-99; H. Witney, "The Mathematics of Physical Quantities: Part II, Quantity Structures and Dimensional Analysis," American Math. Monthly, 75(1968) pps. 227-256; D. Krantz, et. al., Foundations of Measurement, (New York: Academic Press, 1971) pps. 459-464, for an extensive treatment of quantity structures.

15. Ellis, op cit, p. 41 and Chapter 3.

16. Ibid, p.128.

17. See Bridgman, op cit, Chapter 2; Campbell, op cit, pps. 267-294 and 378-399; Ellis, op cit, pps. 55 and 118; and Krantz, et. al., op cit, pps. 502-

503, which not only discuss these concepts, but also suggests additional supplementary concepts of measurement and some alternatives.

18. See. Frits De Jong, Dimensional Analysis for Economists, (Amsterdam: North-Holland Publishing Co., 1967) pps. 6-7 for similar explication of the concept of magnitude.

19. Ellis, op. cit, pps. 133-142.

20. The quantity structure model follows closely Krantz, et. al., op cit, pps. 459-464 and Witney, op cit, pps. 227-256.

21. Ellis, op cit. p. 139.

22. Krantz, et. al., op cit, p. 460.

23. See references in footnote 14 for an extensive development of important axioms, theorems and operations involving quantity structures.

24. Focken, C. M., Dimensional Methods and Their Applications, (London: Edward Arnold and Company, 1953) pps. 24-25.

25. Bridgman, op cit, Chapter 2.

26. Huntley, H. E., Dimensional Analysis (New York: Dover Publications, 1967) pps. 36-37.

27. Langhaar, H. L., Dimensional Analysis and Theory of Models, (New York: Wiley and Sons, 1951) Chapter 4.

28. Bridgman, op cit, p. 20.

29. See Krantz, et. al., op cit, section 10.5 for examples of the procedure.

30. Focken, op cit, p. 27; Krantz, et. al., op cit, pps. 456-457; and Bridgman, op cit, Chapter 5.

31. See M. Brodbeck, "Models, Meanings and Theories," Symposium on Sociological Theory, ed. L. Gross (Evanston, 1959) for an explication of this use of the concept model.

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35. Starling, Electricity and Magnetism (1926) p. 386, quoted in Huntley, op cit, p. 115.

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39. Kuhn, T., The Structure of Scientific Revolutions, (Chicago: University of Chicago Press, 1962) Chapters 6, 7, and 8.

Human Resources in Saudi Arabia

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Human Resources in Saudi Arabia

INTRODUCTION - Part I

Human resources in Saudi Arabia are modeled here as a flow process (see R.E. Wendell, August 1974). The flow process "sees" the population of Saudi Arabia at any given time as divided into a collection of mutually exclusive and exhaustive categories. Persons "flow" from one category to another over a time horizon according to specified transitional constants. To illustrate, a person might move from intermediate education to secondary education with a probability of .2, whereas probability of moving from secondary to intermediate might be .0. A matrix containing all transition probabilities, called the total transition matrix, together with a baseline vector of numbers of persons within each category generates vector descriptions of Saudi human resources.

<u>Notation</u>:

t = time index

p^t = population at t

n = number of categories in human resources description vector

T^t = an $(n \times n)$ matrix of transition constants. This matrix will be assumed to be filled with real numbers rather than functions of time.

M^t = an $(n \times 1)$ vector description of Saudi human resources at t. Note that the sum of entries equals population at t.

<u>Basic Relationship</u>:

$$M^{t+1} = T^t * M^T$$

Vector description of human resources at $t+1$ equals total transition matrix multiplied by vector description at t.

Discussion:

Several tasks present themselves. One is to select the categories which make up the vector description of the human resources sector. This problem was addressed in a pragmatic manner. Categories were chosen, in part, according to the existence of data. Another consideration in the selection of these categories was that we would like to be able to address questions of industrial, oil, and agricultural expansion with these categories. The vector selected, m1, . . . m15, is:

m1 = persons in unstructured pool

m2 = " " elementary school

m3 = " " intermediate school

m4 = " " secondary school

m5 = " " teacher training school

m6 = " " technical and adult school

m7 = " " universities (Saudi and non-Saudi)

m8 = petroleum wage earners

m9 = non-petroleum wage earners

m10 = civilian governmental employees

m11 = military governmental employees

m12 = non-industrial wage earners

m13 = self-employed non-agricultural

m14 = self-employed agricultural

m15 = persons having moved through human resources

The next problem is to collect data to estimate a baseline M vector and transition constants. Collection of data and specification of a baseline M vector are in Part 2. The estimation of transition constants is found in Part 3.

BASIC DATA - Part II

The second section of "Human Resources in Saudi Arabia" will consist of the data used for the analysis. There are two broad kinds of data in the analysis. First, there are primary or direct data. These are data reported in some source, such as a statistical abstract. Secondly, there are derived data. These are data generated by The Project for Theoretical Politics. In the following exposition, direct data will be presented first, followed by derived data.

The first bit of data is about the Saudi Arabian educational system. Other bits of primary data include work force division sizes as a percentage of the total work force and United Nations population estimates. These pieces of direct information are used to generate Table IV.

Table I Educational Data

Year	m2	m3	m4	m5	m6	m7	TOTAL
69/70	383,644	43,455	8,917	9,631	50,521	14,604	510,429
68/69	252,207	33,547	6,913	2,173	44,932	12,416	457,570
67/68	234,726	30,676	5,834	2,093	44,134	10,903	415,115
66/67	212,674	20,279	3,428	3,438	45,913	9,399	295,131
65/66	193,140	18,497	2,876	5,245	36,877	7,917	264,552
64/65	174,514	14,832	2,484	7,556	37,407	6,479	243,272
63/64	156,780	13,768	2,290	6,876	28,619	5,177	213,510
62/63	139,338	11,148	1,997	5,576	25,440	4,601	188,100
61/62	122,905	9,229	1,547	4,395	19,570	3,391	
60/61	104,203	7,875	1,136	3,497	11,184	2,899	

Data for this table are taken from the Saudi Arabian Statistical Abstract 1970.

Table II Manpower Data

Manpower Category	Percentage of Total Work Force
Petroleum wage earners	1.0
Non-petroleum, industrial wage earners	.8
Civilian governmental employees	9.0
Military employees	6.0
Non-industrial wage earners	8.2
Self-employed, non-agricultural	1.0
Self-employed, agricultural	74.0
TOTAL	100.0

	Number of Persons 1964	1972
Private		1,140,000
Public		160,000
TOTAL	1,000,000	1,300,000

Category percentages are taken from Rugh, 1973[1]. Total labor estimates fall between those in the Hammad dissertation and the Rugh article.

Table III Population[2]

	1963	1972
Population	6,420,000	8,200,000

---

[1] "Emergence of a New Middle Class in Saudi Arabia" The Middle East Journal V. 27, No. 1.

[2] United Nations Demographic Yearbook 1973

Derived Constants

Granted the two point fixes on the labor force an annual growth constant of 1.03 fits available data. Similarly, a constant of 1.028 is selected for population data. Primary data, together with these constants yield a derived table, Table IV.

Table IV

Year	Population	Education	Labor	Unstructured Pool
1963	6,420,000	188,100*	970,874	5,261,026
1964	6,597,000*	213,510*	1,000,000	5,383,490
1965	6,781,000	243,272*	1,030,000	5,537,490
1966	6,968,000	264,552*	1,060,900	5,642,548
1967	7,164,000	295,131*	1,092,727	5,776,142
1968	7,359,000	415,115*	1,125,509	5,818,376
1969	7,563,000	457,570*	1,159,274	5,946,156
1970	7,773,000	510,429*	1,194,052	6,068,519
1971	7,988,000	--	1,229,874	--
1972	8,200,000*	--	1,250,000	--
1973	8,437,000	--	1,304,773	--

* indicates direct data

Table IV was generated by (1) establishing entries for the population column by means of applying the population growth constant to U.N. data (page 4), (2) transcribing educational data (3) generating labor data by means of estimates for 1964 and 1972 together with labor force growth constant (4) and finally subtracting education and labor sectors of the population from the total population. The unstructured pool of Table IV is, as the name suggests, a body of Saudis about whom we know little. Ignorance of such vast proportions are mitigated to some extent by the supposition that roughly half of the pool consists of women. Since women in Saudi society are systematically excluded from labor and to a lesser extent from education,

ignorance as to the status of Saudis with respect to our model of that society is not so great as it might appear.

From Tables I, II, and IV, a baseline data vector for 1970 is constructed.

$$M^{1970} = \begin{bmatrix} 6{,}068{,}519^{*} \\ 383{,}644 \\ 43{,}455 \\ 8{,}917 \\ 9{,}631 \\ 50{,}521 \\ 14{,}604 \\ 11{,}940 \\ 9{,}552 \\ 107{,}465 \\ 71{,}640 \\ 97{,}912 \\ 11{,}941 \\ 883{,}600 \\ 0 \end{bmatrix}$$

*See page 2, Part 1

CONSTRUCTION OF TRANSITION CONSTANTS - Part III

Recall the basic relationship of the flow model, $M^{t+1} = T * M^{t}$. For the purpose of vector and transition probability estimation the human resources module decomposes into (1) unstructured pool; (2) educational system; and (3) labor force.

$$\begin{bmatrix} \text{pool} \\ \hline \text{education} \\ \hline \text{labor} \end{bmatrix}^{t+1} = \begin{bmatrix} \multicolumn{3}{c}{A1 \quad \mid \quad A2} \\ \hline A7 & \multicolumn{1}{|c|}{A3} & A4 \\ \hline A8 & \multicolumn{1}{|c|}{A6} & A5 \end{bmatrix} * \begin{bmatrix} \text{pool} \\ \text{education} \\ \text{labor} \end{bmatrix}^{t}$$

Transition Sub-blocks

A_1 and A_2 together give us ml^{t+1} as a function of m^t. Because this is an unstructured pool of persons it is assumed that a growth constant is acceptable. That is to say that A_1 will be a constant and A_2 a vector filled with zeros. ml^{t+1} is modeled as a function of only ml^t.

A_3 - Is intra-educational transitions. Here flow through the Saudi educational system is modeled.

A_4 - Is labor to education transition. The constants for moving from labor back into education are here.

A_5 - This is the intra-labor transition matrix. Here constants for moving from one sector of labor to another are given.

A_6 - Education to labor matrix. These constants model flows from the Saudi educational system into the labor sector.

A_7 - This block gives movement from the unstructured pool at t into the educational system at t+1.

A_8 - This block models direct movement from the unstructured pool at t into the labor force at t+1.

Table V

Category Data Used for Estimation

	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1965	5,537,490	174,514*	14,832*	2,484*	7,556*	37,407*	6,479*	103,000	8,000	92,700	61,800	84,460	10,300	762,200
1966	5,642,548	193,140*	18,497*	2,876*	5,245*	36,877*	7,917*	106,090	8,240	95,481	63,650	80,994	10,609	785,066
1967	5,776,142	212,674*	20,279*	3,428*	3,438*	45,913*	9,399*	109,273	8,487	98,345	65,500	89,604	10,927	808,620
1968	5,818,376	234,726*	30,076*	5,834*	2,093*	44,134*	10,903*	112,551	8,742	101,296	67,530	92,922	11,255	832,900
1969	5,946,156	252,207*	33,547*	6,913*	2,173*	44,932*	12,416*	115,927	9,004	104,335	69,560	95,060	11,593	857,900
1970	6,068,519	268,689*	38,930*	8,479*	9,631*	50,521*	14,604*	119,405	9,274	107,465	71,640	97,912	11,941	883,600

*indicates direct data

Columns m8, . . ., m14 are generated from percentages, Table II and, from labor category entries, Table IV.
m1 is direct from Table IV.

Estimation Procedure for Transition Constants

The construction of transition constants that provide a reasonable representation of the data in Table V and yield yearly vector predictions is the task at hand. Procedures with various error minimization techniques and known statistical properties are available. Rather than blindly apply such techniques knowledge of the Saudi system is modeled into the total transition matrix, followed by error minimization procedures. To illustrate, we go through the teacher training institutions estimation, m5. It is known that these institutions are of secondary level. Because of this, m5 is assumed to be a function of itself, i.e., those who have begun the teacher training program and have neither matriculated nor dropped out, and of intermediate education, m3. It is expected that people don't jump from elementary to secondary education. Accordingly, m2 is given zero for a transition constant. Similar reasoning holds for the unstructured pool. We don't expect people to back up in the educational system resulting in the zero transition from universities. Although people might move from one secondary sort of education to another, it is not modeled into our transition matrix, hence zeros for m4 and m6. Finally, we don't allow movement from the labor pool back to teacher training. Such movement is modeled into adult education.

In the above style of reasoning, free variables are selected according to intuition and conventional wisdom. A final transition constant is computed so that the model will match data sequences for each category. This is accomplished by computing absolute deviations, summing deviation, averaging the sum and dividing by averaged input pool size.

e.g., $m_i(t+1) = x_1(m_i t) + x_2(mjt)$

Time	Size of m_i category	$x_1\ m_i(t)$	Error
t+1	n_1	$x_1\ n_2$	$\mathrm{l}n_1 - x_1\ n_2\ \mathrm{l}$
t	n_2	$x_1\ n_3$	$\mathrm{l}n_2 - x_1\ n_3\ \mathrm{l}$
t-1	n_3	$x_1\ n_4$	$\mathrm{l}n_3 - x_1\ n_4\ \mathrm{l}$
t-2	n_4	$x_1\ n_5$	$\mathrm{l}n_4 - x_1\ n_5\ \mathrm{l}$
t-3	n_5	$x_1\ n_6$	$\mathrm{l}n_5 - x_1\ n_6\ \mathrm{l}$
t-4	n_6	$x_1\ n_7$	$\mathrm{l}n_6 - x_1\ n_7\ \mathrm{l}$

x_2 = average error/average mj

Σ of error
average error
average of mj

ml: estimation of unstructured pool

As already mentioned, this category is treated as if ml^{t+1} is a function of ml^t. The following procedure for estimation was used: the absolute value of yearly data (see Table IV) minus average site of unstructured pool was taken, summed and divided by its n. This number, an average absolute deviation was divided by average site of pool yielding a constant.

Year	Data	Average Size	Deviation
1964	5,383,490	5,684,034	300,544
1965	5,537,490	5,684,034	146,544
1966	5,642,548	5,684,034	41,486
1967	5,776,142	5,684,034	92,168
1968	5,818,376	5,684,034	134,342
1969	5,946,150	5,684,034	262,116
1970			

162,867 = .022
$ml^{t+1} = 1.022\ ml^t$

Total Deviation = 977,200
Total/N = 162,867

m2: elementary education

It was decided that $m2^{t+1} = f(m1^{t}, m2^{t})$. Furthermore, the form and content were chosen as:

$$m2^{t+1} = .75m2^{t} + x_{1}m1^{t} + c_{2}$$

.75 was chosen due to the nature of Saudi education. It is patterned on the U.S. scale of 1-6 elementary followed by three years of intermediate and secondary, respectively.

1970 was the first year for which female statistics are available. Therefore, constants are based on male only data. Baseline data, however, includes female students.

$t+1$	$m2^{t+1}$	x_1m2^t	Error
1970	268,689	189,155	79,534
1969	252,207	176,045	76,162
1968	234,726	159,506	75,220
1967	212,674	144,855	67,819
1966	193,140	130,889	66,241
1965	174,514	117,585	56,929

SUM OF ERROR = 421,905

AVERAGE ERROR = 70317.5

AVERAGE OF ml = 5,684,034

x2 = 70317.5/5, 684,034 = .01237

m3: intermediate education

$m3^{t+1} = x_1m3^t + x_2m2^t$ is an assumed relationship. .5 is picked for x_1. x_2 is derived.

$t+1$	$m3^{t+1}$	x_1m3^t	Error
1970	38,930	16,774	22,156
1969	33,547	15,338	18,209
1968	30,076	10,140	20,536
1967	20,279	9,249	11,030
1966	18,497	7,416	11,081
1965	14,832	6,884	7,948

SUM OF ERROR = 90,960

AVERAGE ERROR = 15,160

SUM OF ELEMENTARY = 1,224,041

AVERAGE ELEMENTARY = 204,007

x2 = 15,160/204,007 = .075

m4: secondary education

$m4^{t+1} = x_1 m4^t + x_2 m3^t$ is the assumed relationship. Picking .5 for x_1, x_2 is derived.

t+1	$m4^{t+1}$	$x_1 m4^t$	Error
1970	8,479	3,457	5,022
1969	6,913	2,917	3,996
1968	5,834	1,714	4,120
1967	3,428	1,438	1,990
1966	2,876	1,242	1,034
1965	2,484	1,145	1,339

SUM OF ERROR = 18,101

AVERAGE ERROR = 3016.8

SUM OF m3 = 131,599

AVERAGE m3 = 21,933

x_2 = 3016.8/21,933 = .1375

m5: teacher training schools

$m5^{t+1} = x_1 m5^t + x_2 m3^t$ is the assumed relationship. .5 is picked for x_1, x_2 is derived.

t+1	$m5^{t+1}$	$x_1 m5^t$	Error
1970	9,631	1,087	8,544
1969	2,173	1,047	1,126
1968	2,093	1,719	374
1967	3,438	2,623	815
1966	5,245	3,778	1,467
1965	7,556	3,438	4,118

SUM OF ERROR = 16,444

AVERAGE ERROR = 2740.7

SUM OF m3 = 131,599

AVERAGE m3 = 21,933

x_2 = 2740.7/21,933 = .1249

m6: technical and adult school

$m6^{t+1} = x_1 m6^t + x_2 m3^t + x_3 m1^t$ is the assumed relationship.

x_1 x_1 is .5 and x_2 is chosen as .1. x_3 is derived.

t+1	$m6^{t+1}$	$x_1 m6^t$	$x_2 m3^t$	Error
1970	50,521	22,466	3,355	24,700
1969	44,932	22,067	3,068	19,797
1968	44,134	22,957	2,028	19,149
1967	45,913	18,439	1,850	25,624
1966	36,877	18,704	1,483	16,690
1965	37,407	14,310	1,377	21,720

SUM OF ERROR = 127,680

AVERAGE ERROR = 21,280

AVERAGE ml = 5,684,034

x_3 = 21,280/5,684,034 = .0037

m7: university

$m7^{t+1} = x_1 m7^t + x_3 m6^t$ is the assumed relationship. x_1 and x_2 are picked at .7 and .1, respectively. x_3 is derived.

t+1	$m7^{t+1}$	$x_1 m7^t$	$x_2 m4^t$	Error
1965	6,479	3,624	248	2,607
1966	7,917	4,535	288	3,104
1967	9,399	5,542	343	2,756
1968	10,903	6,579	583	3,741
1969	12,416	7,631	691	4,094
1970	14,604	10,691	848	3,065

SUM OF ERROR = 41,803

AVERAGE ERROR = 6,934

SUM OF m4 = 237,432

AVERAGE m4 = 39,572

x_3 = 6,934/39,572 = .1749

m8: petroleum wage earner

$m8^{t+1} = x_1 m8^t + x_2 m3^t + x_3 m1^t$ is the assumed relation. .9 and .01 are picked for x_1 and x_2. x_3 is derived.

t+1	$m8^{t+1}$	$x_1 m8^t$	$x_2 m3^t$	Error
1965	103,000	90,000	138	12,862
1966	106,090	95,481	148	10,461
1967	109,273	98,376	185	10,712
1968	112,551	98,346	203	14,002
1969	115,927	101,296	307	14,324
1970	119,405	104,334	335	14,736

SUM OF ERROR = 77,126

AVERAGE ERROR = 12,854

AVERAGE OF m1 = 5,684,034

$x_3 = 1218.8/5{,}684{,}034 = .000214$

m9: non-petroleum wage earners

$m9^{t+1} = x_1 m9^t + x_2 m3^t + x_3 m1^t$ is the assumed relationship. .9 and .01 are chosen for x_1 and x_2. x_3 is derived.

t+1	$m9^{t+1}$	$x_1 m9^t$	$x_2 m3^t$	Error
1965	8,000	6,990	111	899
1966	8,240	7,200	138	902
1967	8,487	7,416	148	923
1968	8,742	7,638	185	919
1969	9,004	7,868	203	933
1970	9,274	8,104	307	863

SUM OF ERROR = 5,439

AVERAGE ERROR = 906.5

AVERAGE m1 = 5,684,034

$x_3 = 906.5/5{,}084{,}034 = .000159$

m10: civilians employed by government

$m10^{t+1} = x_1 m10^t + x_2 m4^t + x_3 m5^t + x_4 m6^t + x_5 m7^t + x_6 m1^t$ is the assumed relation. .9, .1, .133, .1, .067 are picked for $x_1 \ldots x_5$, respectively. x_6 is derived.

t+1	$m10^{t+1}$	$x_1 m10^t$	$x_2 m4^t$	$x_3 m5^t$	$x_4 m6^t$	$x_5 m7^t$	Error
1965	92,700	81,000	229	913	2,862	347	7,349
1966	95,481	83,430	248	1,004	3,741	435	6,623
1967	98,345	85,933	288	698	3,688	530	7,208
1968	101,296	88,511	343	457	4,591	629	6,765
1969	104,335	91,166	583	278	4,413	751	7,144
1970	107,465	96,719	691	289	4,493	832	4,441

SUM OF ERROR = 39,530

AVERAGE ERROR = 6588.3

AVERAGE m1 = 5,684,034

x_6 = 6588.3/5,684,034 = .001159

m11: military personnel

$m11^{t+1} = x_1 m11^t + x_2 m4^t + x_3 m5^t + x_4 m6^t + x_5 m7^t + x_6 m1^t$ is the assumed relation. .9, .1, .133, .1, .067 are picked for $x_1 \ldots x_5$, respectively. x_6 is derived.

t+1	$m11^{t+1}$	$x_1 m11^t$	$x_2 m4^t$	$x_3 m5^t$	$x_4 m6^t$	$x_5 m7^t$	Error
1965	61,800	54,000	229	913	2,862	347	7,349
1966	63,650	55,020	248	1,004	3,741	435	6,623
1967	65,500	57,290	288	698	3,688	530	7,208
1968	67,530	59,000	343	457	4,591	629	6,765
1969	69,560	60,780	583	278	4,413	751	7,144
1970	71,640	62,600	691	289	4,493	832	4,441

SUM OF ERROR = 16,757

AVERAGE ERROR = 2,793

AVERAGE m1 = 5,684,034

x_6 = 2,793/5,684,034 = .000491

ml2: non-industrial wage earners

$$ml2^{t+1} = x_1 ml2^t + x_2 m3^t + x_3 m4^t + x_4 m5^t + x_5 m6^t + x_6 m7^t + x_7 ml^t$$

Assume $x_1 = .9$, $x_2 = .01$, $x_3 = .1$, $x_4 = .133$, $x_5 = .1$, and $x_6 = .067$.

t+1	$ml2^{t+1}$	$x_1 ml2^t$	$x_2 m3^t$	$x_3 m4^t$	$x_4 m5^t$	$x_5 m6^t$	$x_6 m7^t$	Error
1965	84,460	73,800	111	229	913	2,862	347	6,198
1966	80,994	76,014	138	248	1,004	3,741	435	5,414
1967	89,604	78,295	148	288	698	3,688	530	5,957
1968	92,922	80,644	185	343	457	1,591	629	6,073
1969	95,060	83,630	203	583	278	4,413	751	5,202
1970	97,912	85,554	307	691	289	4,493	832	5,746

SUM OF ERROR = 34,590

AVERAGE ERROR = 5,705

AVERAGE ml = 5,084,034

x_7 = 5,765/5,684,034 = .001014

ml3: self-employed non-agricultural

$ml3^{t+1} = x_1 ml3^t + x_2 m3^t + x_3 m3^t + x_2 ml^t$ is the assumed relationship. .9 is picked for x_1, x_2 is assumed. .01, x_3 is derived.

t+1	$ml3^{t+1}$	$x_1 ml3^t$	Error
1965	10,300	9,000	1,300
1966	10,609	9,270	1,339
1967	10,927	9,548	1,379
1968	11,255	9,834	1,421
1969	11,593	10,130	1,463
1970	11,941	10,434	1,507

SUM OF ERROR = 8,409

AVERAGE ERROR = 1,401

AVERAGE ml = 5,684,034

x_2 = 1,401/5,684,034 = .000246

ml4: self-employed agricultural

$ml4^{t+1} = x_1 ml4^t + x_2 m2^t + x_3 ml^t$ is the assumed relationship.

.9 and .1 are picked for x_1 and x_2. x_3 is derived.

t+1	$ml4^{t+1}$	$x_1 ml4^t$	$x_2 m2^t$	Error
1965	762,200	666,000	15,678	80,522
1966	785,066	685,980	17,451	81,635
1967	808,620	706,559	19,314	82,747
1968	832,900	727,758	21,264	83,880
1969	857,900	749,610	23,472	84,818
1970	883,600	772,110	25,271	86,219

SUM OF ERROR = 499,821

AVERAGE ERROR = 83303.5

AVERAGE ml = 5,684,034

$x_3 = 83303.5/5{,}684{,}034 = .0147$

ml5: persons having moved through human resources sector.

Once people have entered this category they are of no interest to us. No records are kept. $ml5^{t+1}$ is conveniently a function of all other variables at t.

Total Transition Matrix

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Basic Data
1.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,068,519
.0124	.75	0	0	0	0	0	0	0	0	0	0	0	0	0	383,644
0	.075	.5	0	0	0	0	0	0	0	0	0	0	0	0	43,455
0	0	.1375	.5	0	0	0	0	0	0	0	0	0	0	0	8,917
0	0	.1249	0	.5	0	0	0	0	0	0	0	0	0	0	9,631
.0037	0	.1	0	0	.5	0	0	0	0	0	0	0	0	0	50,521
0	0	0	.1	0	.1479	.7	0	0	0	0	0	0	0	0	14,604
.000214	0	.01	0	0	0	0	.9	0	0	0	0	0	0	0	11,940
.000159	0	.01	0	0	0	0	0	.9	0	0	0	0	0	0	9,552
.00116	0	0	.1	.133	.1	.067	0	0	.9	0	0	0	0	0	107,465
.000491	0	0	.1	.133	.1	.067	0	0	0	.9	0	0	0	0	71,640
.001014	0	.01	.1	.133	.1	.067	0	0	0	0	.9	0	0	0	97,912
.000246	0	.01	0	0	0	0	0	0	0	0	0	.9	0	0	11,941
.0147	.1	0	0	0	0	0	0	0	0	0	0	0	.9	0	883,600
0	.09	.1	.1	.1	.115	.1	.1	.1	.1	.1	.1	.1	.1	0	0

COMMENTS - Part IV

Some interesting problems surface in developing the flow model of Saudi human resources. We known exactly where we would like to have better information. In general, we would like to have primary data strings for each of our categories. As the model currently stands, these strings are derived from work force estimates and percentages that are ten years out of date. Secondly, we would like to know where people in Saudi Arabia typically move with respect to our categories. It is one thing to claim "Saudi's don't move from labor positions back to teacher training" and quite another to know that this is the case. The transition matrix, although fitting data strings, is user constructed and could have been done entirely differently with equal data matching performance.

The questions we would really like to get at, or perhaps the ones that the Saudi's would like to get at, are untouched by our analysis. Specifically, we are interested in the behavior of the transition matrix over time. How do the transition constants change? Are they controllable in the technical sense of being functions of variables that are purposively manipulable or at least potentially purposively manipulable by the Saudi government? These questions are assumed out of existence by the constant nature of our transition matrix. Rather than being an interesting control throttle for our decision stratum, human resources becomes as much an external constraint as length of daylight and temperature.

One advantage of the current formulation of human resources is that it can be easily re-estimated. Another is that should someone invent a process which generates transition constants it could be programmed as a sub-routine without necessitating a redesign of the human resources module.

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A Revised Agricultural Sector Simulation Model for Saudi Arabia*

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The Context*

Oil clearly has been a dominant factor in the economies of the oil-producing countries of the Middle East. Yet, to focus entirely upon oil is to view a rather distorted picture of these countries. For despite the tremendous wealth derived from oil production, there has been little appreciable change in the overall economic situation in these countries. But then the economic development of each country depends upon much more than the accumulation of capital surpluses, upon more than the growth in productivity of a single economic sector. It also depends heavily upon the modernization and development of other economic sectors, particularly the agricultural sector.

Recognizing the importance of the agricultural sector to the economies of these oil-producing countries we have attempted to construct a simulation of that sector as viewed by the decision-makers in each country.[1] More precisely, we have sought in this paper to formulate a structure which will enable us to (1) identify and trace the various information and material flows in the agricultural production process that influence the decision-makers' choices of developmental policies and programs, and (2) project the consequences that their choices might have for the outputs of the agricultural sector. To this end, we have adopted what we term a "building-block" approach to modeling the agricultural sector.

With this "building-block" approach, the complex array of variables and relationships comprising the agricultural sector is conceptually

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grouped into several sequentially-linked "logical components" (or building blocks) to simulate various facets of the production process. Four such components are included in the present version of our model: resource allocation, modernization, production, and consumption/demand components. The output from each component serves as either an input to another component or a performance measure, or both. The final outputs of the model thus include not only physical outputs, but also a set of performance measures. It is this set of measures which the decision-makers evaluate and compare with policy goals when choosing their policies and programs for the next time period.

At present, then, we have a model which is structured to simulate the production of field crops (specifically wheat, the principal crop and food staple in the five oil-producing countries examined here). Parameter values as well as initial values for the variables have been collected for Saudi Arabia. Utilizing these values we have made several test runs of the model. The results of these preliminary runs suggest that despite some apparent substantive and technical short-comings in the model, the relationships expressed in the model are logically consistent. Moreover, the outputs generated during these runs seem to make sense substantively.

The Setting: Agriculture in the Middle East

Agriculture constitutes a major sector of both the economy and the social structure of each of the five Middle Eastern countries examined in this study. After oil, it is the largest single contributor to the national accounts (i.e., the national income, the GNP, the balance-of-payments, etc.) of each country. And, whereas

the oil sector represents the major source of revenue for these countries, the agricultural sector is the principal source of employment and individual income. More than half of the population in each country (except Libya) derive their livelihoods directly from agricultural production. In Libya's case this figure is considerably smaller (approximately one-third of the population), but it still represents the largest share of the population involved in any one sector of the Libyan economy.

Despite this rather sizable input of labor into the agricultural sector, agricultural productivity in these countries remains rather low. Winter grains such as wheat and barley, (the principal grain crops in these countries), for example, rarely yield more than fifteen bushels per acre per year, even in relatively good years.[2] At such levels of productivity, these countries are barely able (if at all) to produce enough on their own to meet the present needs of their respective populations. All too often they must import large quantities of food to "fill up" their frequently-deficient food accounts. Confronted with ever-growing populations and rising demands for better standards of living, their countries are thus likely to become even more dependent upon external sources of food. In an age where these countries are fervently trying to establish their economic independence, the prospect of becoming increasingly dependent upon other countries for food would clearly seem to represent an anathema. But unless agricultural productivity can be significantly raised above present levels (or otherwise augmented), these countries are likely to experience widespread famines in the not-too-distant future.

To avert the possibility of famine, considerable efforts are thus being made in these countries to modernize and develop their agricultural sectors. If these efforts are to succeed, however, several rather formidable obstacles must be overcome. One such obstacle which has long constrained agricultural production in these countries is their relative lack of adequate water supplies.

For the most part, these countries depend upon rainfall to provide the water needed for crop production. But because of the arid nature of the climate in these countries, the rainfall is both low and highly variable over time. Many areas of these countries, in fact, received so little rain as to make the production of rainfed crops well-nigh impossible. As a result, the amount of cultivable land in each country is limited to a very small percentage of each's total land area. And where this land is actually put under cultivation, the utilization of this land for rainfed crops (which the major share of the crops grown in most of these countries are) requires the adoption of such practices as placing the cropped area in fallow during alternate growing seasons. Under such conditions it is hardly surprising that these countries have thus far been unable to realize their full agricultural potential.

The alternative to this dependence upon rainfall for crop production is, of course, the extension of irrigation to the areas to be cultivated (both present and potential). But to bring these areas under irrigation requires that these countries have alternative sources of water in sufficient amounts to meet the water requirements of the area (and crop) to be irrigated. Of the five countries, however, only

Iraq appears to be endowed with such a supply of irrigation water. Specifically, with a combined average annual flow of around 61 million acre-feet, the Tigris and Euphrates rivers provide Iraq with great irrigation potential.[3] Utilizing only part of this potential (i.e., approximately 28.4 million acre-feet), the Iraqis can presently put an estimated 7.5 million acres of crop land under irrigation.[4]

The other four countries do not possess any readily-accessible supplies of irrigation water which are comparable to those found in Iraq. Iran, it is true, also relies upon the Euphrates for irrigation water. The amount of water it extracts from this source is considerably less than that extracted by Iraq, however. And as such, this source is, by itself, insufficient to meet Iran's present and projected water needs. The situation is even bleaker for Algeria, Libya and Saudi Arabia; there are no rivers, lakes, etc., of any potential significance in these countries.

From where, then, can these four countries get the water they need for irrigation? One source is to be found underground, i.e., groundwater from underground streams and lakes. Information on how extensive the supply of this water is, however, is rather scanty. A more certain source of potential irrigation water is, of course, seawater. But the production costs involved in tapping this source, as well as those associated with groundwater, are substantial. The cost of producing groundwater, for example, presently runs around \$130 per acre-foot.[5] This contrasts sharply with the cost of desalinated water which, given present technology, costs an estimated one dollar per 1000 gallons, or about \$326 per acre-foot.[6] As these countries have to dig deeper wells, and as desalination technology

advances, however, the difference in the costs of these two alternative sources is likely to diminish.[7] But for the present time (and for the foreseeable future), it is the production of groundwater which, in terms of cost, constitutes the more practical solution to the water problem in these countries.[8]

Whatever the source, it is abundantly clear that the development of irrigation is an essential component of any effort to raise agricultural productivity of these five countries. However, expanded irrigation is not the only prerequisite for increased agricultural production: "Indeed, neither water nor any other single input is the magic wand that will quickly and painlessly produce agricultural plenty and prosperity".[9] Thus, if the expansion of irrigation in the cultivated areas is to be of any value, it must be accompanied by a number of additional but equally important production inputs. After all, the scarcity of water does not constitute the only obstacle to the expansion of agricultural production in the five countries.

Another major obstacle to increased agricultural production is the general lack of soils suitable for cultivation. Suitable soils are as scarce in these countries as water, if not more so. As a consequence, only a small fraction of the land in each country is truly cultivable. Even in those areas where cultivation is feasible, the suitability of the soil is limited. In particular, there are two aspects of the soils in these countries which pose major limitations upon agricultural production. First, with continued wetting and drying out, the soil has a tendency to accumulate a high concentration of salt. This problem is especially great in Iraq where between twenty and thirty percent

of the cultivable land has to be abandoned each year due to salination. Second, the soils are very low in nitrogen content. Nitrogen is necessary to sustain high production in these soils. As a consequence of both limitations, the productivity of the soil tends to be exhausted rather quickly with the result that much of the cultivated land must be placed in fallow during alternate years. Moreover, even when this land is cropped, the resulting yields tend to be quite low.

Clearly, then overcoming this second obstacle constitutes another major prerequisite for increased agricultural production. But again, no single input will be sufficient to achieve this. Instead, there are several separate but closely interrelated inputs which should help improve the suitability of the soils for production. Among these is, first of all, the construction of a drainage system for "flushing" harmful salts out of the soils. In conjunction with this, these countries need to improve their use of land and water. What this specifically entails is the adoption of such practices as land leveling, flood control, and moisture conservation. Additionally, more extensive use must be made of fertilizers, particularly nitrogen fertilizers. Both potassium and phosphorus fertilizers are available in these countries, but not in sufficient amounts to sustain a wide variety of crops at high production levels. From oil, however, these countries could derive the needed amounts of nitrogen fertilizer, although this would require sizable investments in the development of the appropriate production facilities. Finally, with increased fertilization and irrigation, new varieties of crops could be introduced which are of the high-yield type.

All of the inputs identified above, including the extension of irrigation, are directed at raising the per acre yields of the cultivated lands in these countries. But raising per acre yields represents only one aspect of the overall problem of increasing agricultural production. Another equally important aspect of this problem is that of raising the per capita productivity of labor.

As we noted at the beginning of this report, a major share of the population (and thus the labor force) in each of the five countries is engaged in agriculture. Yet, the per capita productivity of agricultural labor is presently quite low. Faced with insufficient water supplies and poor soils, the individual farmer, of course, is not going to be very productive. But even with the necessary inputs to overcome these two obstacles, he is still not likely to be very productive. For to raise the per capita productivity of agricultural labor in these countries, two obstacles must be overcome. The first of these relates to the availability of labor in sufficient numbers to support an intensive effort to expand agricultural production.

Of those employed in the agricultural sector, most are engaged in traditional subsistence farming. With agricultural production thus being directed primarily at meeting the food needs of the individual household (or production unit), the labor input required to produce this food is provided principally by the household itself. And, more often than not, this labor is sufficient to meet the labor requirements for subsistence farming. With the movement away from subsistence farming and toward expanded production, however, ". . . . the need for labor will increase so considerably that present surpluses (if any

exist at all) will hardly suffice to satisfy the new requirements."[10] Put somewhat differently, by raising production yields these countries are likely to create another problem for themselves, namely, the problem of shortages of labor. There are no other sources of labor in sufficient amounts which these countries can draw upon to meet prospective labor requirements. The situation is further aggravated by the fact that the agricultural sector loses part of its labor supply each year. This loss of labor results not only from normal attrition (e.g., death, retirement, etc.), but also from the movement of sizable numbers from the rural areas to the cities.

How, then, is the problem of labor shortages to be overcome? One way, of course, is to substitute machinery for human labor, i.e., to "mechanize" the agricultural sector. At present the level of mechanization in these countries is rather low; farmers still depend largely upon human and animal power. Thus, to increase the per capita productivity of the existing labor supply (and, in turn, to decrease the amount of labor required for the intensification of agricultural production), these countries will have to input sizable amounts of farm machinery (e.g., tractors, harvestors, etc.). Farm machinery, in this sense, constitutes both a labor-saving device and a means to increase production.

But is the inputting of this machinery enough? To reiterate a point made earlier, the introduction of any single input (such as farm machinery) is not by itself sufficient to bring about the desired changes in agricultural production. Thus, ". . . . mechanization would accomplish relatively little unless accompanied by better

irrigation and drainage, greater fertilizer use, better crop varieties, better control of weeds and crop diseases, and by other components of a technologically advanced agriculture. . . ."[11]

Nor is the mere inputting of these factors of production together enough. There must also be a willingness on the part of individual farmers to adopt these production inputs. What this essentially boils down to is the existence of economic opportunities that are rewarding to these farmers. Herein lies the final obstacle to increased agricultural production to be discussed here, namely, the relative lack of such opportunities in these five countries.

As Schultz (1964) has noted, traditional agriculture (which agriculture in these countries predominantly is) has certain built-in resistors to any change in the existing state of the art: "The concept of traditional agricultures implies long-established routines with respect to all production activities."[12] And because farmers in traditional agriculture have a wealth of experience with these routines to draw upon, the risks and uncertainties associated with the production possibilities of traditional factors of production are minimal. But with the introduction of new factors of production, these farmers are faced not only with having to break with the well-established practices of the past, but also with having to cope with risks and uncertainties which are as yet unknown.[13] As a result, they are likely to be rather hesitant to adopt these new factors. Yet, it is only through experience that they will be able to learn what the risks and uncertainties inherent in these factors are.

But how are those engaged in traditional agriculture to be induced to try these new production inputs? The answer to this question lies in the economic opportunities that agricultural production and, in turn, the use of these new inputs offer to the farmer. More precisely, the willingness of individual farmers to adopt the new production inputs depends largely upon (1) the payoffs to their production activities, and (2) the costs (as well as the supply) of these inputs. What this essentially means is that there must be a system of prices which will enable farmers to make a reasonable margin of profit and, at the same time, to obtain the necessary new inputs at prices that permit this profit margin. It is this margin of profit, then, that provides the necessary inducement, or lack thereof, to adopt the new production inputs.

In the five countries examined here, however, such a system of prices is, for the most part, missing. Prices for farm products in these countries generally tend to be depressed and distorted. Moreover, the costs of the required inputs remains quite high. The overall effect of the present system of prices thus has been to leave farmers in these countries with relatively small margins of profit, if any at all. As a result, there is little incentive for them to produce much more than what is necessary to meet their own consumption demands, let alone to purchase the new production inputs.

Clearly, the establishment of a more efficient system is essential to overcome this final obstacle. But again, the overcoming of this one obstacle is not, by itself, enough to bring about an increase in production. True, an efficient system of prices is likely

to lead to an increased willingness on the part of farmers to grow more, but their efforts will not get very far unless there are adequate supplies of the necessary production inputs available.

In sum, then, the essence of agricultural development in these five Middle Eastern countries lies in

> . . . the application of a package of separate <u>but closely interrelated</u> programs, technologies, and processes; it is their interrelationship which is truly significant. . . Any single program may have limited and sometimes even negative effect, if taken by itself; but may be highly productive if combined with other programs in proper proportions and proper timing.[14]

The problem facing decision-makers in these countries thus is one of finding that proper combination of programs, in the proper sequence, which will produce the results they seek.

As the preceding discussion indicates, the effort to modernize the agricultural sector in the five countries examined here is clearly no simple matter. There are numerous physical, economic, social and political factors, the dynamic interactions between which affect the decision-makers' choices of developmental policies and programs. To provide a clearer picture of how this complex array of factors and their interrelationships affect these choices, we have constructed a simulation model of the agricultural sector in these countries. What this model purports to offer is a way (1) to identify and trace the essential information and material flows influencing the decision-makers' choices, and (2) to analyze and project the consequences that their choices might have for the performance of the agricultural sector.

To simplify the picture even further, we have confined our attention in the construction of this model to the production of but one crop:

wheat. This narrowing of focus is based, in part, on the fact that wheat constitutes the principal crop grown in these countries in terms of both the quantity produced and the amount of crop land devoted to it. Moreover, wheat represents the major staple in the diets of the people in these countries. Finally, we contend that even with this focus on one crop we will still be able to present a fairly representative picture of the setting within which decisions on the development of the agricultural sector are made in these countries. That is to say, we hold that the structure of the model (i.e., the equations) will remain similar whether we are dealing with the production of wheat, barley, dates, or vegetables. What will change, of course, are the values for the parameters and variables included in the model. But now let us look at the model itself.

In constructing our model of wheat production, we have employed what we shall term a "building-block" approach.[15] Basic to this approach is the assumption that the system to be modeled is composed of several functionally interrelated "building-blocks." Linking these components are the outputs of the components themselves. That is to say, each component yields an output (or set of outputs) which serves either as an input to another component in the system, or as a measure of the component's performance. Collectively, the performance measures generated by these components comprise a "performance vector" which, in turn, serves as an input to the decision stratum (i.e., as the information upon which the decision-makers' base, for the most part, their choices for the next time period).

The Model

This section will describe the four components (resource allocation, modernization, production, and consumption/demand) which make up the agricultural sector model. Simplifying assumptions have, of necessity, been made in each component. However, for the sake of clarity each component's description will be brief and (for the most part) the simplifying assumptions will be considered in a separate section at the conclusion of this paper.

Considerable revision of the model has been undertaken. The changes correct errors which were discovered in earlier versions and also make the model more appropriate for use in simulating the wheat sector of Saudi Arabia. Still, the model should be considered an initial effort which will doubtless require revision. Suggestions or comments from readers of this paper are encouraged and will be gratefully received.

A. RESOURCE ALLOCATION

The first component (or "building block") deals with the allocation of resources for wheat production. First we shall consider the allocation of land.

In our model, the amount of cultivable land available is assumed to remain constant throughout the simulation run. This assumption is based on the further contention that it will be some time (say thirty years or so) before these countries are likely to make any marked progress towards expanding the amount of cultivable land. Not all of this cultivable land, of course, is actually cultivated at any one time. Both the nature of the soils and the prevailing farm practices necessitate the placing of some of this land in fallow each growing season.

A distinction is made between rainfed land, which is farmed with traditional methods, and irrigated land, which is farmed with modern methods. We assume that for Saudi Arabia the amount of rainfed land available is constant throughout a simulation run. The policy-maker may only influence the amount of this land that is used for wheat production. This is expressed in the following equation:

TOTRFAW = P1*TOTRFA (R1)

where: TOTRFAW = rainfed land to be used for wheat production (hectares)

TOTRFA = total rainfed land (hectares)

P1 = the proportion of total rainfed land to be used for wheat production (dimensionless)

On rainfed land in most of Saudi Arabia, however, cropland may be used only every other year. Thus we have the equation:

RFAWEAT = 0.5*TOTRFAW (R2)

where: RFAWEAT = the amount of rain-fed land available for wheat production in any given year (hectares)

The allocation of irrigated land is somewhat more complex; a policy-maker must determine how much irrigated land is available each year as well as decide how much of the available land is to be devoted to wheat production. The amount of irrigated land available at any time is a result of past expenditures on irrigation development, and hence the amount of land available at some future time is dependent upon present expenditures. Our model includes the following assumptions about irrigation development projects:

1) Any development project will take a known time to complete.

2) A project provides no additional irrigation capability until construction is complete.

3) Construction cost of a project accrues in equal annual installments during the construction period.

Thus, the following equations represent the process of planning for a new irrigation development project:

IRRNU = BUDI/COSTI (R3)
CALL INPIPE (IRRIG, IRRNU, IRRDELA) (R4)
CALL UNICOST (IRRCOST, BUDI, IRRDELA) (R5)

where: IRRNU = the amount of water to be provided by a given new irrigation development project (m^3/year) [m^3= cubic meters].

BUDI = the total amount budgeted for the (entire) cost of the project ($).

COSTI = the cost per m^3 per year of the irrigation development project ($/$m^3$/year).

CALL INPIPE invokes a computer subroutine which delays the appearance of the new irrigation water until a certain number of iterations (equal to the number of years needed for construction of the project) has occurred.

IRRIG = a variable which is part of the INPIPE subroutine.

IRRDELA = the number of years required for this particular project to be completed (years).

CALL UNICOST invokes a computer subroutine which keeps track of both the total annual costs for all irrigation development projects underway at a given time, and the number of years remaining until each project is completed.

IRRCOST = a variable which is part of the UNICOST subroutine.

It should be apparent that the model must also yield a figure for any new irrigation water which becomes available during the current iteration. This is done through the following equation:

IRD = OUTPIPE (IRRIG) (R6)

where: IRD = irrigation development rate; the amount of water becoming available as a result of the completion of one or more irrigation development projects during the current iteration (m^3/year).

OUTPIPE (IRRIG) invokes a computer subroutine which determines, from stored information on earlier irrigation development project planning decisions, how much new water becomes available during the current iteration.

The following equations provide for the determination of how much irrigated land will be available and for the allocation of part of that land to wheat production. The equations also allow for the assumption that irrigated land resulting from recent irrigation development projects should tend to be double-cropped. Thus, we keep track of both the actual land devoted to wheat and the cropped land devoted to wheat, where the latter is the number of physical hectares times the average number of crops grown on them per year.[16]

$$IRP = IRD/IRR + IRP \qquad (R7)$$

$$IRRWEAT = NUCROP*IRP*P2 + OLDCROP*IRA*P3 \qquad (R8)$$

$$TOTWEAT = RFAWEAT + IRRWEAT \qquad (R9)$$

$$LUC = TOTRFA + IRA + IRP \qquad (R10)$$

$$LCW = RFAWEAT + IRA*P3 + IRP*P2 \qquad (R11)$$

$$IRRTOT = IRA + IRP \qquad (R12)$$

where: IRP = new irrigated land resulting from the completion of irrigation-development projects (hectares).

IRR = the amount of water required for very high yield wheat production assuming double-cropping (m^3).

IRRWEAT = total irrigated cropped land allocated to wheat production (hectares).

NUCROP = cropping ratio (ratio of cropped land to physical land) for new irrigated land (dimensionless).

OLDCROP = cropping ratio for old irrigated land (land irrigated but not as part of a modern irrigation development project) (dimensionless).

IRA = total old irrigated land (hectares).

P2 = proportion of new irrigated land to be allocated to wheat production (dimensionless).

P3 = proportion of old irrigated land to be allocated to wheat production (dimensionless).

TOTWEAT = total <u>cropped</u> land allocated to wheat production (hectares)

LUC = total physical land under cultivation (hectares)

LCW = total physical land allocated to wheat production (hectares)

IRRTOT = total irrigated physical land under cultivation (hectares)

B. THE MODERNIZATION COMPONENT

As we have noted so often in this paper, the development of a single input (e.g., water) is not by itself sufficient to bring about increased agricultural production. Instead, a number of separate (but closely interrelated) modernizing inputs are required, including fertilizers, farmzmachinery, improved seed varieties, etc. In order to explore the impact of these modernizing inputs upon agricultural production, a "modernization" component has been built into the model. This component focuses specifically on the impact of two such inputs on the production of wheat in the five countries: fertilization and mechanization. The principal output of this component is azmeasure of productivity (yield per hectare).

There are two main influences on productivity of land if water is adequate. They are the level of fertilization and the level of mechanization. The levels of usage of fertilizer and modern machinery and the effects of those levels of usage enter into this component through the following equations:

RFERT = BUDF/GVPFERT (M1)

FERTA = 1000* RFERT/IRRWEAT (M2)

RMECH = BUDM/GVPMECH (M3)

ATP = (1-(1/WEAROUT))*ATP + RMECH (M4)

POWU = ATP/IRRTOT (M5)

YPHM = MIN (YLDF(FERTA), YLDM(POWU)) (M6)

YPH = (YPHT*RFAWEAT + YPHM*IRRWEAT)/LCW (M7)

where: RFERT = the amount of fertilizers obtained by the government for a given year (metric tons).

BUDF = the amount budgeted (and spent) by the government for purchase of fertilizers during a given year ($).

GVPFERT = the government's price of fertilizer. This is a weighted price for nitrogen, phosphate, and potash fertilizers purchased in the proportion 5:2:2 ($/metric ton).

FERTA = the fertilizer application rate (kg/hectare).

IRRWEAT = the amount of irrigated cropped land devoted to wheat (see earlier definition in Resource Allocation component) (hectares).

RMECH = the amount of mechanization obtained by the government for a given year (hp).

BUDM = the amount budgeted (and spent) by the government for the acquisition of new and replacement tractors during a given year ($).

GVPMECH = the government's price of farm tractors ($/hp).

ATP = available tractor power. This is the total of all available operative tractors (hp).

WEAROUT = the average expected useful life of a tractor (years).

POWU = the average rate of power (tractor) utilization (hp/hectare).

IRRTOT = total irrigated land (hectares).

YPHM = yield per hectare (modern). This is the average yield for land farmed with modern methods (kg/hectare).

MIN( ) is a function which selects the lowest of the values enclosed in parentheses. Here it selects either YLDF (FERTA) or YLDM (POWU), whichever is lower.

YLDF (FERTA) = a function which relates the wheat yield to fertilizer application rate, assuming adequate water and mechanization (See Appendix I) (kg/hectare).

YLDM (POWU) = a function which gives the wheat yield possible with any given level of mechanization, assuming adequate water and fertilization (See Appendix II) (kg/hectare).

YPH = average overall yield for wheat (kg/hectare).

YPHT = yield per hectare (traditional). This is the average yield on rainfed land with traditional methods (kg/hectare).

LCW = total land in wheat production (hectares).

With regard to the above equations, two points should be kept in mind. First, there is no provision for the accumulation of fertilizers over time. Such a provision may easily be added if it should turn out to be needed. However, we assume that because of the low quality of the soils in these countries farmers will use all of the fertilizer they are able to get. Second, we assume that the productivity of traditional (rainfed) land will remain constant throughout the simulation run since so little of that land is susceptible to modern capital-intensive methods. This is the case for wheat in Saudi Arabia, at least.

C. THE PRODUCTION COMPONENT

The third component in our model deals with production and with the returns (or losses) to the farmers and to the government as a result of wheat production activities. The following set of equations makes up this component:

YLD = .ØØ1*YPH*LCW (P1)

OUTC = PCON*YLD (P2)

OUTE = YLD-OUTC (P3)

```
GVCOST = (GVPFERT-FMPFERT)*RFERT + (GVPMECH*
         RMECH - FMPMECH*ATP)*  (LCW-RFAWEAT)/
         (IRP + IRA)                                (P4)

TINC = DMPRICE*YLD - FMPFERT*RFERT - FMPMECH*
       ATP                                          (P5)

INCPC = TINC/SALF                                   (P6)

INCH = TINC/LCW                                     (P7)

LABP = YLD/SALF                                     (P8)
```

where: YLD = total production actually achieved (metric tons).

OUTC = quantity of wheat produced which is allocated to domestic consumption (metric tons).

PCON = proportion of wheat production allocated to domestic consumption. This is a policy variable expressed as a decimal value between Ø and 1.Ø (dimensionless).

OUTE = quantity of wheat produced which is available for export (metric tons).

GVCOST = net cost to the government of subsidizing modern wheat farming practices through provision of fertilizer and machinery ($).

FMPFFRT = farm price of fertilizer. This is the price paid by the farmer ($/metric ton).

FMPMECH = farm price of mechanization. This is the cost to the farmer of using 1 hp for one year ($/hp-year).

TINC = total income (net) for all farmers ($).

DMPRICE = domestic price of wheat (price received by farmers) ($/kg).

INCPC = average net income from wheat per agricultural person ($/man).

SALF = size of the agricultural labor force engaged in growing wheat.

INCH = average net income from wheat per hectare of land usedz in wheat production ($/hectare).

LABP = a measure of labor productivity: the average yield per person engaged in growing wheat (kg/man).

D. CONSUMPTION/DEMAND COMPONENT

This final component in our proposed model essentially represents a budgetary accounting mechanism. It takes information on production outputs (from the production/marketing component) and computes the values for several variables measuring the overall performance of the production process being modeled. Put more simply, the purpose of this component is to compute the final set of variables comprising the performance vector. These variables include the value of crop exports (Equation C1) and the demand for food imports (Equation C3).

VALEXP = WP*OUTE (C1)

DWHEAT = BASED*(POPI/100 + ELAST*(INDXPCE/POPI - 1.0) (C2)

IMPORT = DWHEAT - OUTC (C3)

POPI = (1 + POPGR)*POPI (C4)

where: VALEXP = total value of wheat exported ($).

WP = world price for wheat ($/metric ton).

DWHEAT = consumption demand for wheat for the current year (See Asfour, p. 25) (metric tons).

BASED = consumption demand for food in a base year (metric tons).

POPI = index of population for the current year relative to the base year (dimensionless).

ELAST = elasticity coefficient of demand for wheat (dimensionless).

INDXPCE = index of total private consumption expenditure for the current year.

IMPORT = imports of wheat required during the current year in order to meet demand.

POPGR = annual proportional increase in population (expressed as a decimal value) (dimensionless).

E. DISCUSSION

Perhaps the most critical change present in this revised model of the agricultural sector is that of ignoring the microeconomic behavior of the individual farmer. It is assumed that the adoption of modern farming methods will occur only when heavy subsidization of the required inputs and intensive efforts by agricultural extension teams are present. This seems reasonable, since the adoption of modern methods as a result of extension work alone has been minimal in Saudi Arabia.[17] In addition, since there exists no true country-wide price and/or transport system, the price paid to the farmer in a subsidized program will likely be controlled (either directly or indirectly) by the government.

Thus, in our model we assume that:

a) all fertilizer is bought by the government and resold to to the farmers;

b) all tractors and other mechanized equipment is bought and maintained by the government, and rented to individual farmers;[18] and

c) the government pays the total cost of constructing and operating water development projects.

We also assume that the government is willing to absorb a reasonable loss in subsidizing the production of wheat in order to lessen the country's dependence on imports.

Thus our model may be seen to be structured almost totally around the policy-maker. The costs involved are costs to the government. The computed average income per person engaged in wheat production, for instance, is really more a social indicator for the policy-maker than a measure of earned income and economic strength in a free market sector. The government controls the farmers' incomes through setting prices on

wheat, fertilizer, and machinery. And so on.

To the extent that this image of the agricultural sector in Saudi Arabia is correct, the model may not be too far off the mark. If these simplifying assumptions are found to be unwarranted, however, then considerably more detail may be necessary in the model. Given the difficulty of obtaining reliable (let alone extensive) data on Saudi Arabian agriculture, however, this model seems a reasonable beginning.

APPENDIX I

YIELD RESPONSE TO FERTILIZER ASSUMING ADEQUATE WATER AND LEVEL OF MECHANIZATION

The function used in this model for giving the yield response to level of fertilization (assuming water and mechanization level are sufficient) is necessarily a hypothetical one. The following comments present the assumptions made in hypothesizing this particular response curve.

First, it was assumed that the shape of the curve would be one in which the slope was steep initially, was less steep and approximately linear through a middle range, fell to zero as some point of maximum possible yield was passed through, and became increasingly negative beyond that point.[1]

Second, the slope of the approximately linear portion of the curve was taken to be 15 kg/kg. This figure was arrived at on the basis of estimates indicating that approximately 2 pounds of nitrogen and .8-1.0 pounds each of P_2O_5 and K_2O would be needed per bushel of wheat produced.[2]

Third, the point of maximum yield was assumed to be slightly greater than the 6720 kg/ha shown in Table 6.3 of Seifert, et al (p. 60). No assertion is made here that this is an accurate estimate of the point of maximum yield; it is simply a point of relatively high yield arbitrarily selected for use in order to permit testing the model's general behavior.

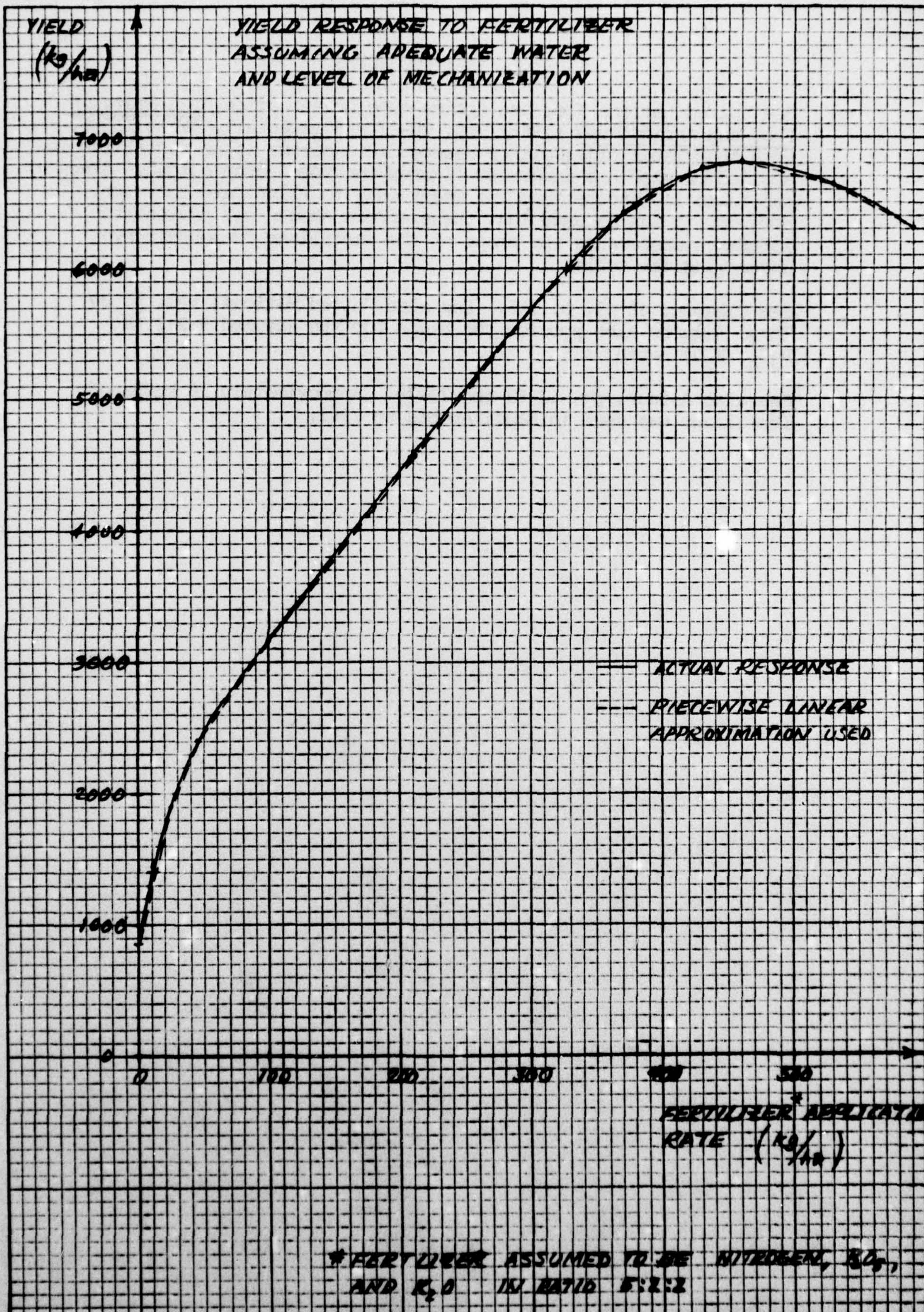
Fourth, points on the low end of the curve were selected on the basis of an assumption of 1400 kg/ha with very little fertilizer and

870 kg/ha with no fertilizer. The first figure comes from Clawson, Landsberg, and Alexander (p. 299). The second is estimated from the same work (p. 228), and is used with the assumption that yields in years from 1951-1957 reflect a virtually zero level of fertilizer utilization.[3]

Fifth, the use of seed varieties responsive to high fertilization levels is assumed.

Once again, the response function shown in Figure A-I is hypothetical, but its general shape should be correct, and the curve itself may be easily changed on the basis of more accurate data.

FIGURE A-I.



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A-I FOOTNOTES

[1]See United Nations Food and Agriculture Organization, The State of Food and Agriculture (1968), pp. 90-91 and especially Table III-5. Note that Table III-5 either assumes zero output if no fertilizer is applied or else has incorrect figures for total crop output. Since the table is hypothetical and meant only to illustrate the text, however, it was assumed that these errors should not prevent the inference concerning the shape of the fertilizer response curve underlying the table.

[2]See Clawson, et al, p. 145. See also United Nations, FAO, p. 89. These figures also provide the basis for the assumed 5:2:2 (N, P_2O_5, K_2O) ratio.

[3]See also Asfour, pp. 62-63 and 73-74. Approximately 10 kg/ha of fertilizer was used in Saudi Arabia in 1961.

APPENDIX II

MECHANIZATION CONSTRAINT ON YIELD RESPONSE TO FERTILIZER ASSUMING ADEQUATE WATER

The function (shown in Figure A-2) for mechanization level required to reach various production levels is even more conjectural than that for yield response to fertilizer. It is assumed here that mechanization is required if high yields are to be obtained; the process of obtaining such high yields requires many more operations (irrigation, fertilization, mechanical harvesting, tillage, etc.) than are required in traditional agriculture. Moreover, high levels of mechanization should permit double-cropping in Saudi Arabia.[1]

Exactly what levels of mechanization are required for particular levels of output (assuming adequate water and fertilizer), however, is highly speculative. Estimates of the need for various levels of mechanization are couched in phrases such as ". . . underpowered at 0.5 horsepower per hectare, and that 1.0 horsepower per hectare would represent overpowering. . ."[2]

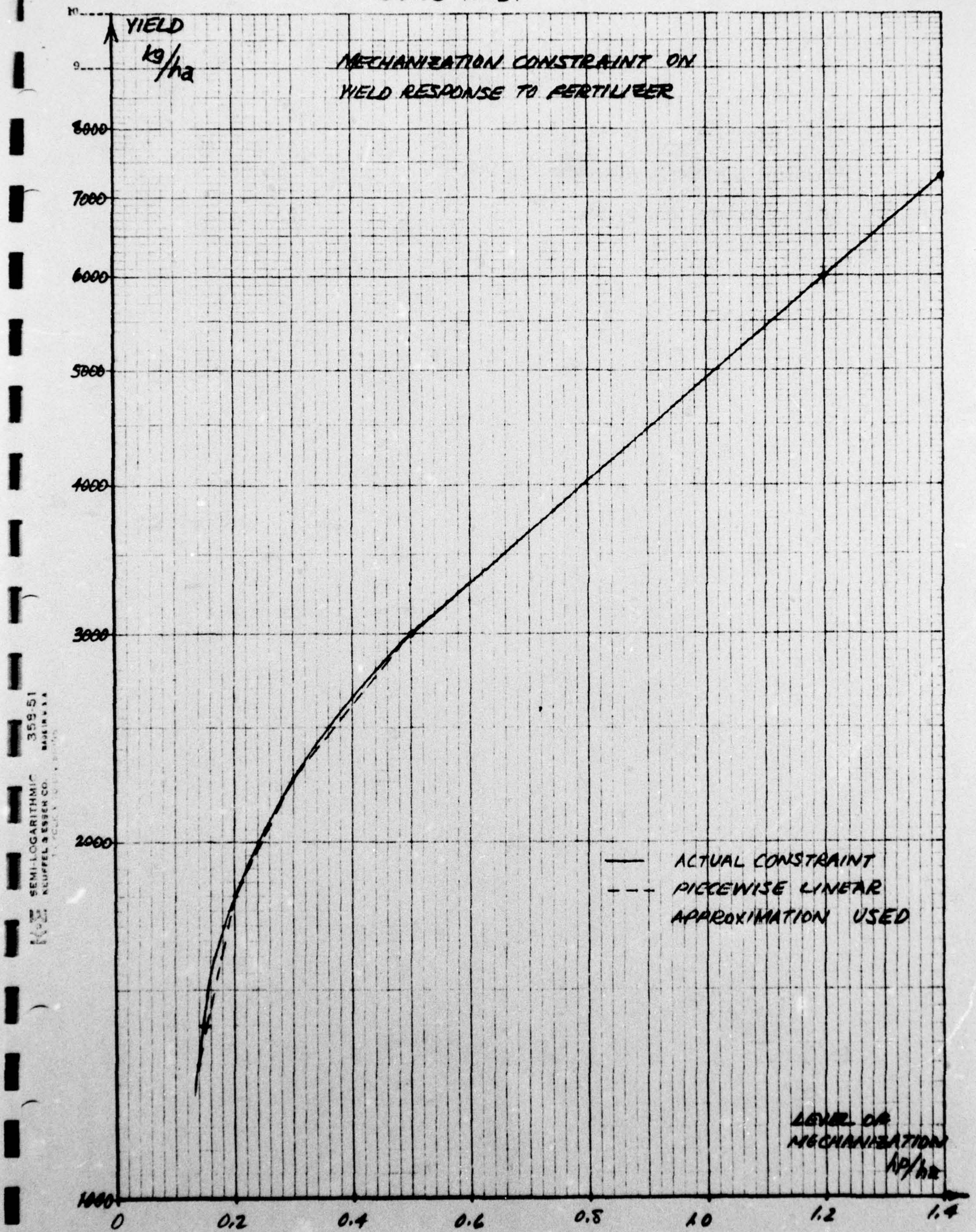
The function used in the model at this time takes its shape from a plot of hp/ha vs. average aggregate yield of major food crops for several nations.[13] Few nations show power utilization levels greater than 1.0 hp/ha, but a level of 1.0 hp/ha generally is associated with only 2300-3400 kg/ha yields. Yields of 5000^{+} kg/ha are shown only for nations using 1.7-2.1 hp/ha.

Hence for this effort a power utilization level of 1.2 hp/ha was arbitrarily chosen as necessary to achieve a 6000 kg/ha yield, Ø.5 hp/ha for a 3000 kg/ha yield, and Ø.2 hp/ha for an 1800 kg/ha yield.

Mechanization and fertilizer are treated as mutual constraints; a high level of fertilization cannot produce a high yield if mechanization sufficient to permit efficient performance of other required operations is not available, and mechanization is of limited utility without fertilizer.

As is the case for the fertilizer response function, the mechanization constraint function should be revised when better data are obtained.

FIGURE A-2.


YIELD kg/ha
MECHANIZATION CONSTRAINT ON
YIELD RESPONSE TO FERTILIZER
ACTUAL CONSTRAINT
PIECEWISE LINEAR
APPROXIMATION USED
LEVEL OF
MECHANIZATION
hp/ha
1000
2000
3000
4000
5000
6000
7000
8000
9
10
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
SEMI-LOGARITHMIC
KEUFFEL & ESSER CO.
359-51

A-II FOOTNOTES

[1]See Seifert, et al, p. 63.

[2]Clawson, Landsberg, Alexander, p. 149.

[3]United Nations FAO, p. 93.

FOOTNOTES

[1]We refer specifically to the following five countries: Algeria, Iran, Iraq, Libya, and Saudi Arabia.

[2]Clawson, Marion, Hans Landsberg and Lyle Alexander (1971) The Agricultural Potential of the Middle East. New York: American Elsevier Publishing Co., Inc. p. 2.

[3]Clawson, Landsberg and Alexander, p. 37.

[4]Ibid.

[5]Clawson, Landsberg and Alexander, p. 115.

[6]Ibid.

[7]As Clawson, Landsberg and Alexander have indicated, it is estimated that the costs for producing groundwater from pumped deep wells runs between $250 and $370 per acre-foot (1971, p. 115). In contrast, Fried Edlund (1971) suggest that with the development of a large-scale single purpose plant based on oil or gas, the cost of desalination could be brought down to around 25 to 35 cents per 1000 gallons, which is equivalent to $81 to $114 per acre-foot.

[8]The use of groundwater is an even more practical alternative in Libya, where along with the continued search for oil has come, in recent years, the discovery of bountiful sources of underground water.

[9]Clawson, Landsberg and Alexander, p. 4.

[10]Brenner, Y.S. (1971) The Economics of Agricultural Development. Ithaca, N.Y.: Cornell University Press, p. 50.

[11]Clawson, Landsberg and Alexander, p. 41.

[12]Schultz, T.W. (1964) Transforming Traditional Agriculture New Haven: Yale University Press, p. 33.

[13]Ibid.

[14]Clawson, Landsberg and Alexander, p. 111

[15]By a "building block" approach, we refer specifically to the modeling approach developed by Glen Johnson, et al, namely "the generalized system simulation approach."

[16]It is important to keep track of this distinction (between cropped and physical land).

[17]See Seifert, et al, pp. 54-55, and Asfour, pp. 73-74.

[18]See Asfour, p. 73, Saudi Arabian Monetary Agency, p. 49, and Saudi Arabia Central Department of Statistics, pp. 72-73.

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Optimization and Arms Races:
A Model-Theoretic Analysis*

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ABSTRACT:

Basic concepts of formal theories and models are reviewed and used for a model theoretic analysis of some of the applications of mathematical methods in theorizing and model construction. The systems theoretic concept of the constructive specification of a model is discussed and optimization, particularly optimal control, approaches to model construction are considered in this light. The results provide a framework in which it is possible to distinguish the analytic requirements of a theory (used to obtain a constructive specification) from substantive requirements. It is argued that a theory can have policy relevance only if the statements of the theory are based on substantive grounds and the model which represents the theory has some established ties with a real system. Since specific results must be specific theory dependent, an analysis of Brito's (1972) paper on dynamic arms races is performed. This paper was selected because it contains a general problem statement and claims policy relevance. It is shown that statements in the Brito theory are included only to meet the requirements of the particular optimal control formulation used. It is also shown that his theory distinguishes between logically equivalent constructive specifications, accepting one and rejecting another.

§ 1 Introduction

As in other areas of social science, international politics theorists are increasingly turning to mathematics for languages in which to express their theories. While examples of specific problem areas which have seen extensive uses of mathematics abound, perhaps the most technically sophisticated are the various extensions to the Richardson analysis of arms races (e.g., Richardson, 1960; Intriligaton, 1964; Brito, 1972; Zinnes and Gillespie, 1973), several of which have analyzed arms races as optimal control problem.

In this paper we adopt a model-theoretic (see §2) perspective to investigate the various roles mathematics might play in problem formulation and theory development and to relate these roles to the various purposes to which the theories might be put. While the argument to be made is general, the specific evidence is specific theory dependent. Therefore much of an analysis will be done on Brito's (1972) paper on dynamic arms races. The Brito formulation was chosen because it is both a very general statement of the arms race problem from the optimal control perspective and is easily accessible. The general conclusions of this analysis are, we believe, applicable beyond the Brito paper. The next section develops the model-theoretic perspective from which we will view the application of optimal control theory to the study of arms races.

§ 2 Varieties of Models and Theories

There are a variety of terms which will be used in a technical sense in developing the argument of this paper. Since these terms (e.g., theory, model, system, etc.) are employed in the international politics literature in a variety of mutually inconsistent ways, it is necessary that some space be devoted to developing rather precise definitions.

The first term to be defined is "theory." Most all uses of "theory" suggest that theories are linguistic, that is they are expressed in some language. In international politics, the language is generally a "natural" one such as Norwegian or English. However, some are expressed in artificial languages such as differential equations (Richardson equations) or DYNAMO (Forrester's World Model). In general, as will be argued below, the language in which a theory is expressed is consequential. Languages are not always interchangeable and propositions which are expressible in one may may not be expressible in another.

Secondly, the sentences in a theory of international politics generally are assertions that some state of affairs obtains in some world; that is, that it is true in some world. For example, one version of Rosenau's adaptation theory contains the sentence "Variations in the structure of a nation are related to changes in the nation's external environment." That the sentences in a theory are asserted to be true world seem to be fairly unobjectionable (for an opposing position see Friedman, 1953). Of course, to assert a sentence to be true does not make it true. Whether particular sentences are accepted as true is largely dependent upon epistemological, methodological, and sociological concerns which are outside the scope of this essay. Truth here is being employed in the sense of Tarski (1944).

Thus far a theory has been said to be a set of sentences each of which is asserted to be true. Since the concern of this paper will be primarily with theories which have some deductive structure relating the sentences, the definition can further be sharpened to read: "A theory, in a technical sense, is a set of sentences where each sentence is asserted to be true and where the set is closed under deduction." That is, the theory set contains any sentence logically implied by any other sentence in the set. Thus, this concept requires some preassigned logical framework such as the predicate calculus. The definition given above is a fairly standard one within the context of the deductive sciences.

In most of the international politics literature, no clear distinction is drawn and maintained between models and theories. Indeed, the common practice is to use "model" and "theory" as synonyms. Thus in some contexts the Richardson equations are termed a "model" of the arms race and in others a "theory" of the arms race. While there is nothing wrong with having synonyms for frequently used words such as "theory," there is a useful technical distinction which can be made between "model" and "theory."

Corresponding to the technical sense of theory defined above, is a technical notion of model where a model for a set of sentences (i.e., a theory) is a set theoretic structure which satisfies those sentences. (This discussion of model is based upon Thorson and Stever, 1974.) More specifically, a set-theoretic structure M is a set of elements (objects), $A = \{a_1, a_2, \ldots\}$ together with a set of relations of order i, $P^i_1 1$, . . ., $P^i_2 2$, and may be expressed

$$M = \langle A;\ P^i_1 1,\ P^i_2 2,\ \ldots,\ P^i_n n,\ \ldots \rangle$$

This idea of a set theoretical structure is important to the development of the argument of this paper and will be returned to below. The point to note here, however, is that A is an abstract set (i.e., collection of objects). No particular domain from which the objects must be drawn has been specified. The elements of A could be numbers (a numerical domain), weapons systems (a political domain), words (a linguistic domain) etc. Quite clearly if the goal is to develop a theory which is empirically descriptive of some aspect of politics, e.g., arms races, some of the elements of A should resemble objects believed to be present in the referent reality being theorized about. The relations in M are subsets of i-fold cartesian products on elements in A. Given a set of theoretic structure which is felt to in some (as yet undefined) sense represent the referent reality, the theorist will want to write down sentences which are descriptive of properties of M. These sentences form a theory of M. As an informal example, the arms race work to be considered below appears to be developing a theory of a set theoretic structure where A consists of two nations, each nation's stock of weapons, a consumption stock for each nation, and money. The relations include reaction rules and utility functions for each nation. In order to develop a theory of such a structure, it is necessary to have a language in which the properties of M can be expressed.

Such language L in which properties of M can be expressed will consist of formulas generated by a specified set of rules, say the predicate calculus, from an alphabet consisting of relation symbols (R_1, R_2, . . .), variable symbols (x_1, x_2, . . .), connectives ($\neg, \wedge, \vee$, . . .), and quantifiers, ($\exists, \forall$). Since functions and constants are special kinds of relations, function symbols (f_1, f_2, . . .) and constant sumbols (c_1, c_2, . . .) will also be used in L. The language L is generally assumed to be first order, that is, its variables range over the elements of A (as opposed to

ranging over the subsets of A, or set of subsets, etc.). Sentences in L are formulas containing no free variables.

Let T be a set of axioms in a language L. If Ø is a mapping of constant symbols occurring in T into the set of objects A, and also a mapping of relation symbols occurring in T into the set of relations in M, then M provides an interpretation of T under Ø. If this interpretation results in the sentences in T being true, then M is said to satisfy T and M is a model of the axiom set T. A model for a set of axioms then, is a set-theoretic mathematical structure which together with the mapping Ø interprets the axioms in such a way that the axioms are true.

The distinction just made between objects and symbols denoting objects (constants) and between relations and relation symbols should be emphasized. The reason for this distinction is that each mapping onto the objects and relations in a structure M provides an interpretation of the symbols in T. This is important since (as will be shown) a given axiom set can have more than one interesting interpretation, and only some of them will be models of the set.

One of the most obvious problems with the above definition of model is what is meant by a sentence being "true." Rather than provide an extended discussion of truth, the reader is referred to Tarski (1944). The notion of truth being employed here is semantic and not "methodological." The important question is not how we know whether a particular sentence is true but rather what is meant to assert a sentence to be true. Roughly the idea of truth being suggested here is similar to that of Aristotle: "To say of what is that it is not, or of what is not that it is, is false, while to say of what is that it is, or of what is not that it is not, is true." However, a semantic definition of truth views "truth" as a relation between sentences of a language and the objects and relations "referred" to by these sentences.

Thus, in the terms of this paper, truth is structure dependent. That is, sentences which are true of one set-theoretic structure will not in general be true of another.

This "model dependence" of truth is quite important to bear in mind in evaluating mathematical theories of "non-mathematical" phenomena since the Tarski definition of truth is the one generally employed by mathematicians and logicians. One consequence of Tarski's definition is that if some set-theoretic structure together with an appropriate mapping serves as a model for an axiom set, then 1) by definition, the axioms are true of the model and 2) all deductive consequences of the axioms i.e., the theory sentences are true of the model. However, being true of one model does not imply anything about being true of other structures (unless these other structures can be shown to stand in some special relation (e.g., isomorphism) to the model. Thus, for example, great care must be exercised in moving from one structure, e.g., a well specified model, to another, e.g., "the real world." While this point will be developed further below, it will be helpful to first illustrate what is meant by model using several examples.

In order to make this definition of model more clear, consider a very simple Theory T' which contains only two axiom sentences.

A1: $(\quad x_1)\ (x_1 R x_1)$

A2: $(\quad x_1)(\quad x_2)(\quad x_3)\ [(x_1 R x_2 \wedge x_2 R x_3) \rightarrow x_1 R x_3]$.

Consider further the following two mathematical structures:

M*: $\langle A; P^2 \rangle$ where A is a finite set of "alternatives" and P^2 is the binary relation "is preferred

and

M**: $\langle L; F^2 \rangle$ where L is the set of "living males" and F^2 is the binary relation "is the father of."

If the symbol R is mapped onto P^2, and the variables are assumed to range over A, then A1 would read "for all alternatives in the set A, it is never

the case that an alternative in A is preferred to itself." Axiom A2 would read: "For any triple of alternatives in the set A, if the first alternative is preferred to the second, and the second is preferred to the third, then the first alternative is preferred to the third." To claim M* to be a model of T' is to assert the truth of these two sentences (A1 and A2). Further, Tarski (1944) shows that asserting a sentence to be true is equivalent to saying it is satisfied by all its objects. Again, there exists no algorithm for determining whether a particular sentence is in fact satisfied by all its objects. However, to assert that T' is modeled by M* is to say that each sentence in T' is satisfied by all its objects.

Let us now examine the relation between the structure M** and the sentences in T'. Do we want to assert that M** is a model of T'? In this case the function maps the relation symbol R onto the relation F^2. Interpreting A1 with M** results in the sentence:

> "For all males in the set of all living males, it is never the case that a male is the father of himself."

To assert that M** is a model for T' is to assert this to be a true sentence. And, indeed, the sentence is empirically true. However, we must be careful not to move hastily from this observation to asserting that M** is a model for T'. The definition of a model requires that all the axioms be true when interpreted by a model. Consider A2. Under M** we have the following sentence:

> "For any three males in L, if $male_1$ is the father of $male_2$, and $male_2$ is the father of $male_3$, then $male_1$ is the father of $male_3$."

Again, to assert M** is a model for T; is to assert the truth of this sentence. Yet this sentence is empirically untrue. Indeed, an ordinary language translation of this sentence would result in the assertion that a grandfather is the father of his grandson. The reason "is preferred to" seems a satisfactory interpretation of R and "is the father of" does not, is that "is preferred to" is generally thought to be a transitive relation (as asserted by A2) and "is the father of" is not transitive. Thus the structure M** is not a model for T'.

Another transitive relation is "is greater than." If the letter "I" denotes the set of integers, and ">" denotes "is greater than," then the structure I,> is a model for T'. A third transitive relation "is greater than or equal to" may be denoted by "$\geq$." Consider whether the structure I,$\geq$ is a model of T'. Clearly axiom A2 is true with this interpretation; however, A1 reads as follows:

> "For any integer, it is never the case that the integer is greater than or equal to itself."

Most of us would assert this sentence to be false and not allow I,$\geq$ as a model for T'.

Hopefully, these simplistic examples provide a general sense of how the terms "model" and theory" are being used in this paper. Moreover, it should be clear from the above discussion that it is possible to develop a theory of models. In Robinson's (1963) words: "Model theory deals with the relations between the properties of sentences or sets of sentences specified in a formal language on one hand, and of the mathematical structures which satisfy these sentences, on the other hand [p.1]."

This notion of model is central to the theory building enterprise.

In theorizing about any phenomena (be it arms races, ethics, or whatever) a necessary first step is to isolate a set of "objects" (variables) with which the theory will be concerned. Each of these objects in turn can take on a number of values. Each of these values is sometimes termed an appearance of the object. For example, suppose some theory of arms races partitioned overall weapons stock into three values or appearances - low, medium, high. From the model theoretic perspective, this means the A component of the mathematical structure $<A; P_j^i>$ will include weapons stock as an object which is itself a set consisting of three elements where each element corresponds to one of the appearances of the object.

Since the arms race work to be examined is based upon systems theory concepts it will be helpful to briefly illustrate the equivalence between a set theoretic structure and an abstract system. In general, theories will not be about phenomena with only one object (e.g., weapons stock) but rather about worlds with "n" objects, $X_1 X_2, \ldots X_n$. A general system can then be defined (Mesarovic, 1968; Windeknecht, 1971) as a relation in the cartesian product of these objects:

$$S \subseteq X_1 \times X_2 \times X_3 \ldots \times X_n$$

The cartesian product of n sets is the set of all ordered n-triples $<x_1, x_2, \ldots x_n>$ where $x_1 \epsilon X_1$, $x_2 \epsilon X_2, \ldots x_n \epsilon X_n$. A relation on the cartesian product of n sets is simply a subset of all ordered n-tuples. Thus any system is a mathematical structure and may serve as a model for a theory. While this definition is quite abstract, it is possible to get from it to the familiar black box with inputs X and outputs Y. This is done by first defining an index set:

$$I = \{1, 2, \ldots n\}$$

and then partitioning I into

$$I_x = \{i_1, i_2, \ldots i_m\}$$

$$I_y = \{i_{m+1}, i_{m+2}, \ldots i_n\}$$

Since this is a partition,

$$I_x \cup I_y = I$$

and

$$I_x \cap I_y = \emptyset$$

Next define an input set X;

$$X = \{x_i | i \epsilon I_x\}$$

and an output set Y

$$Y = \{x_i | i \epsilon I_y\}$$

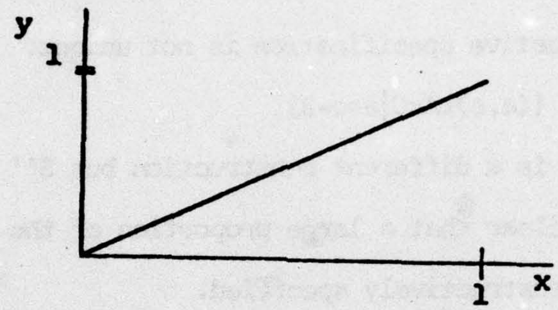
A system can now be defined as a relation on the cartesian product of inputs and outputs, or:

$$S \subseteq X \times Y$$

While this may seem excessively abstract, such a view makes it very difficult to fall into the trap of reifying systems. A system is something the theorist imputes on the objects believed to make up the world. If objects are "badly" picked then statements true of the system will not in general be true of the world. That a system can be imputed reflects the constraints on the allowable conjunctions of appearances the objects in the theorists world are allowed to evince.

Thus, the set theoretic system structure considered above is generally at best a statement of existence made by the theorist. The claim is made that some relation on the specified objects does in fact exist. Unfortunately, except for very simple systems one cannot actually specify the system at this level of abstraction. That is, generally it is impossible to write down or otherwise determine which elements of the cartesian product are contained in the subset S and which are not. This should be expected since even in mathematics very few of the objects and relations of interest

are specified directly and one of the key problems of mathematics is that of the search for bases or generators for various sets (Hammer, 1971). For example, it is not possible to list all of the elements in $S \subseteq X \times Y$, $X=Y=$set of positive real numbers, even when S is graphically represented by the following figure.



It is possible however to express S in terms of the equation of the line, i.e.,

$$S = \{(x,y) \in X \times Y \mid y=x\}$$

The corresponding task for theorists constructing models of systems is constructive specification (Mesarovic, 1968; Windekneckt, 1971).

The process of constructive specification is very familiar and is probably the cause of much confusion in the modeling process. For example, consider:

$$A = \{1, 2, 3\}$$

$$B = \{2, 3, 4\}$$

$$S = \{(1,2), (2,3), (3,4)\} \subseteq A \times B$$

In this example S is actually a function

$$S: A \to B$$

and clearly

$$(a,b) \in S \leftrightarrow b = a+1, \ a \in A$$

where + refers to ordinary addition of real numbers. This observation

allows an alternate description of the set S, that is:

$$S' = \{(a,b)\epsilon A\times B \mid b=a+1\}$$

S' and S are clearly the same set. That is, S was defined by listing its elements and S' was defined by giving a rule which determined its elements. S' is a constructive specification of S which simply means that the elements in S are determined by a specified formula. Further, it is important to note that the constructive specification is not unique. For example:

$$S'' = \{(a,c)\epsilon A\times C \mid a=c-3\}$$

where C = {4, 5, 6}, is a different construction but S'' is the same set as S. It should be clear that a large proportion of the sets considered in mathematics are constructively specified.

In the theory proposed by Mesarovic (1968), the constructive specification of a system is achieved through auxiliary functions (to be defined below) and requires the concept of a state representation of S. Any input output system can be written as a relation

$$S \subseteq X\times Y$$

In general the system will in fact be a relation and not a function. That is, there will generally be more than one output element in Y corresponding to a given, unique input in X. A state representation of X provides sufficient additional information about the system to remove this ambiguity and provide for a unique element in Y given the state and the input. Formally this is achieved by representing the given system as the union of several systems each of which is a function in the mathematical sense (unique inputs gives unique output). That is, let

$$\mathcal{F} = \{f \mid f:X\rightarrow Y \ \&\ f\subset S\}$$

Then, $S = \cup\mathcal{F}$. It is then possible to define a mapping M,

$$M: \mathcal{F}\rightarrow Z,$$

which associated a unique name with each function in $\mathcal{F}$. Z is the set of

labels or names. Then, the system

$$S_z\colon\ Z\times X\to Y$$

can be defined with the property that

$$(z,\ x,\ y)\ \varepsilon\ S_z \leftrightarrow (z,\ y)\ \varepsilon\ S$$

In Mesarovic's terms Z is the global state object of the system and S_z is the global state representation. Essentially, the state $z\varepsilon Z$ defines which function in $\bar{\bar{f}}$ is used to specify the output $y\varepsilon Y$ for a given input $x\varepsilon X$.

The state representation removes ambiguity from the system in an abstract sense but it does not necessarily provide any real insight into the system structure. However, a constructive specification sometimes can be developed to provide such insight. Essentially, a constructive specification is a new system S_c which is in some sense simpler than S and can be used to specify the elements of S. It generally takes the form of some type of algorithm. Roughly, the intent is to provide a mechanism by which given the state (an element in Z) and the input (an element in X) the output can be determined.

A constructive specification typically would have the following structure. Mappings

$$\phi\ :\ \ X\to X_c$$

$$\psi\ :\ \ Y_c\to Y$$

are specified and a new system

$$S_c\colon\ Z\times X_c\to Y_c$$

is determined. To be of use, S_c should be algorithmically determined, i.e., given $z\varepsilon Z$ and $x_c\varepsilon X_c$ a well defined procedure should exist to determine the corresponding element $y_c\varepsilon Y_c$. A constructive specification of S is obtained if:

$$\{(x,y)\varepsilon X\times Y|y=\psi(S_c(z,\ \phi(x))),\ z\varepsilon Z\}\subseteq S$$

We are explicitly assuming the domain of S_z is the cartesian product $Z\times X$.

As an example of the procedure, consider:

$$S \quad X \times Y$$

$$X = \{x_1, x_2\}, \quad Y = \{y_1, y_2, y_3\}$$

$$S = \{s_1, s_2, s_3, s_4\}$$

where

$$s_1 = (x_1, y_1)$$

$$s_2 = (x_1, y_2)$$

$$s_3 = (x_2, y_2)$$

$$s_4 = (x_2, y_2)$$

A state representation is achieved if we define $Z = \{1, 2\}$ and let

$$S_z = \{(1, x_1, y_1), (1, x_2, y_2), (2, x_1, y_2), (2, x_2, y_2)\}$$

A construction specification of this system is now described. Let

$$X_c = \{1, 2\}, \quad Y_c = \{3, 5, 9\}, \quad Z = \{1, 2\}$$

and let

$$S_c = \{(z, x_c, y_c) | Y_c = z + 2x_c \quad z \varepsilon Z, \quad x_c \varepsilon X_c\}$$

Then, with

$$\Phi = \{(x_1, 1), (x_2, 2)\}$$

$$\Psi = \{(3, y_1), (5, y_2), (9, y_3)\}$$

it follows that

$$S' = \{(x,y) | y = \Psi(z + 2\Phi(x)) \; x \varepsilon X, \; z \varepsilon Z\}$$

and $\quad S' = S.$

Notice that given a state and input, say $z=1$, $x=x_1$, we can "compute" y. That is,

$$x_c = \Phi(x_1) = 1$$

$$y_c = z + 2x_c = 1 + 2 \times 1 = 3$$

$$\Psi(y_c) = \Psi(3) = y_1$$

The conclusion is that $(x_1, y_1) \varepsilon S'$ and hence in S.

It should be explicitly pointed out that the use of numbers and arithmetic in the example is not particularly significant. The importance is that a well defined, well understood set of operations was used to determine the elements which appear in S.

It should also be obvious that there is not much utility in the construction for small finite problems. There is no particular advantage in using the constructive specification of S instead of S itself for such a system. However, in general the system S cannot explicitly be written down and constructive specification provides a way of increasing understanding of the structure of the system.

The concepts of auxiliary functions (Φ, Ψ, S_c) and constructive specification are very common in engineering oriented system theories. In fact as Windekneckt points out [Wind., 1971] they are so common that the basic process and the assumptions are often overlooked. Difference equations, differential equations, stochastic processes, mathematical programming, etc., are all standard models methods used by system engineers and systems theorists. A large portion of the systems theory work tends to be the search for more and more general ways of establishing the properties of the systems of concern.

The results of such efforts are invaluable but certain cautions must be taken. It should be clear that the result of a constructive specification is a system

$$S' = \{(x,y) \varepsilon X \times Y \mid y = \Psi(z, \Phi(x)), z \varepsilon Z\}$$

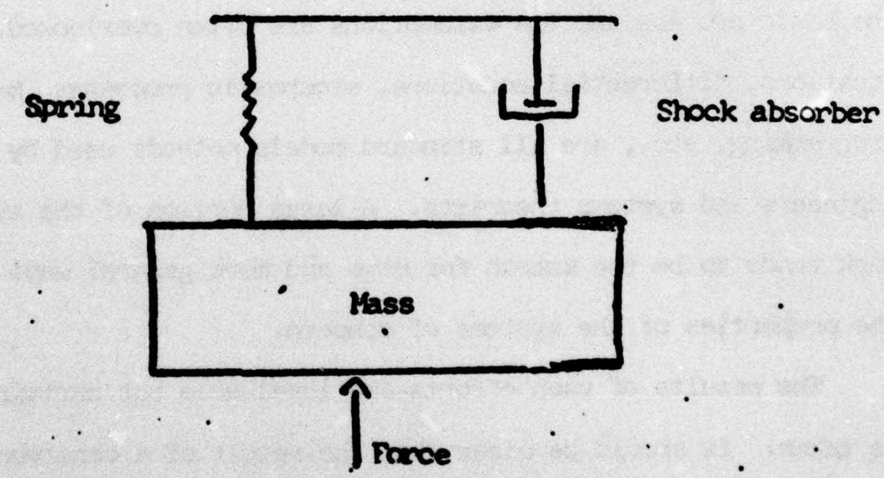
It is not within the realm of the constructive specification procedure to establish that $S' \subseteq S$ or even to establish some lesser form of equivalence between the systems.

In many instances the system S is not carefully specified even to the degree of defining the objects, Without a definition of S the mappings Φ and Ψ cannot be defined and by default are implicitly assumed to be

identity mappings with $X=X_c$ and $Y=Y_c$. The system model is then the logical result of the specification and nothing more.

Another point can also be made. The global state object defined earlier as well as the global state representation were introduced as mathematical artifacts. Substantive analysis of the system is always required if they are to have any meaning or interpretation. The analyst or theorist is not at liberty to assume a specification procedure and consider his results truth in anything but the system S'.

To better illustrate the point consider an engineering problem of describing the time behavior of the displacement from equilibrium of the mass in the simple mechanical system in the diagram below for various applied forces. It is very reasonable to assume that the diagram accurately reflects the actual interconnections of components in the system.



With forces as a function of time and displacement from equilibrium as a function of time as basic objects an engineer would probably establish mathematical time functions

$$S: T \to R$$

$$X: T \to R$$

to describe displacement and force respectively. He would then proceed with

a differential equation

$$\frac{md^2x(t)}{dt^2} + \frac{cdx(t)}{dt} + kx(t) = f(t)$$

where m, c, k denote mass, damping constant, and spring constant respectively; x(t) and f(t) are real numbers representing displacement and force at time t respectively, i.e., $t \epsilon T$, $f(t) \epsilon R$, $x(t) \epsilon R$. All numbers are interpreted with respect to established scales of measurement.

The engineer would then use the algorithm (differential equation) to find mathematical functions in X which satisfy the equation for a given function in F representing force. The resulting solutions are his model of the system. The differential equation is his constructive specification.

The point of the example is that the engineer has confidence that his model accurately represents the behavior of the physical system over a specified range of conditions. This confidence arises from an understanding of each component (spring, mass, shock absorber) and confidence in the physical principles used in establishing the behavior of the components when connected in the system. Each part of the model can be justified and interpreted on physical grounds.

If the engineer were asked to construct the same system model without knowledge of the system itself but given several graphs of time histories described as inputs and outputs, he conceivably could obtain the same differential equation using data analytic technique. However, even though the resulting equation and system model is the same as that derived above, the engineer does not have the same degree of understanding of the physical system modeled. In the later case he does not have any interpretation for additional variables brought into the model ($\frac{d^2x}{dt^2}$, $\frac{dx}{dt}$, m, k, c). He furthermore cannot ensure that his model will describe the "real" system behavior for any inputs other than those on which the model derivation was based.

Under the conceptualization developed here, systems based theory building involves theorizing about at least three and sometimes four distinct set theoretic structures. The first, the "referent reality" is not knowable directly and knowledge of it is mediated by perception and cognition as well as measuring devices. Based upon this indirect knowledge, a set of variables and relations is posited (the model, S) and a theory of this model (sentences which are true of it) is developed. If S is a good representation of the referent reality, then the theory will be descriptively useful in making statements about the referent reality. However, often S will be too complex to specify it constructively and to thereby develop useful theories of it. In such cases it is necessary to develop another structure, S', which is constructive and which therefore may permit the development of interesting theory. In the best case, S' will be related to S in the sense that there exists (in the sense of Zeigler, 1971) a behavior preserving morphism from S to S'. That is, S' preserves the input-output relations in S. A theory of S' is useful in making predictions about the behavior of S but will in general not be very helpful in assessing the effect of "reorganizations" of S. Thus, to the extent policy advice concerns other than input changes, S' may not be helpful in giving policy advice even if S is known to correspond well to the "referent reality" and S' preserves input-output relations in S.

Finally, even S' may not be tractable for certain purposes. For examples, if all the inputs and outputs in S' have disturbance terms associated with them, it may be difficult to say certain sorts of things about S'. In such cases a fourth structure S_m may be constructed. S_m might be an optimal control formulation which is reached by further simplifying S'. Again statements true of S_m will not generally be true of S. This is not to say that statements about S_m may not provide insight into S, but only that one

should be very wary of using optimization models of the arms race as "...an effective framework within which critical policy issues can be explored (Brito, 1972:374)."

In order to illustrate this last point, it is necessary to consider a particular theory of the arms race. Since the 1972 Brito formulation is one of the most general of the optimization formulations we will again return to it and examine the adequacy of both the theory and the model. Our method will be to critique the model and the theory by demonstrating the questionable and highly implausible statements which the model and theory support. Such an attack is legitimate given the deductive nature of the Brito theory. If this is a theory in the technical sense, then the theory must contain all sentences deducible from the assumptions. The theorist is not free to pick and choose among the deductions those which he wishes to retain and those he wishes thrown out.

§ 3 Construction Specification based on Optimization Methods

As developed, the process has at least three basic parts,

1) a model $S \subseteq X \times Y$

2) a specification

$$\Phi: X \to X_c$$

$$\psi: Y_c \to Y$$

$$S_c: Z \times X_c \to Y_c$$

3) the constructively specified model

$$S' = \{(x,y) \in X \times Y \mid y = \psi(S_c(z, \Phi(x))),\ z \in Z\}$$

The basic system model S is presumably based on substantive analysis of the system and is a model of some theory consistent with empirical evidence. Notice that even in the ideal case when $S' \subseteq S$, the model S' and the model S are only behaviorally equivalent in the sense that input pairs appearing in S' appear in S. There is no requirement that ϕ, ψ or S_c have any particular substantive interpretation. Particularly, one cannot conclude that the artificially produced objects used in the specification actually illuminate the structure of the system S. The best one can say is that S behaves as if it performed the operations used by S_c; one cannot say S performs those operations.

This is particular true of models S' based on optimization procedures. A model specified with optimization notions typically has the following structure. The system model is again

$$S \subseteq X \times Y$$

but the specification assumes the existence of a decision maker who selects the inputs in a particular manner. That is,

$$S_c: Z \times X \to Y$$

and

$$P: S_c \to V$$

are stated, where S_c is the system model and P the performance function

which evaluates possible appearances of the system S_c. V is a value set and is partially ordered by some relation, denoted here by $\leq$. We assume $S_c = X$, $Y_c = Y$ for clarity only.

With this structure, it is assumed that the decision maker selects the elements in X corresponding to each state $z \varepsilon Z$ so that

$$P(z,x^*,y^*) \leq P(z,x,y) \ \forall \ x \varepsilon X$$

That is, the decision maker selects inputs x^* corresponding to a given state z which then establishes the output y^*. This appearance of S_c satisfies the partial order relation on V and hence determines which appearances are acceptable. The model S' is then

$$S' = \{(x^*,y^*) \varepsilon X \times Y \mid P(z,x^*,y^*) \leq P(z,x,y) \quad z \varepsilon Z\}$$

Only solutions to the optimization problem are included in the model S'.

Such optimization or maximum principle approaches to model generation are used in Langrangian mechanics in physics for example. The reader is referred to Samuelson (1971) for an excellent discussion of such methods. Again however, the result is a behavioral model, i.e., $S' \subsetneq S$ and the optimization itself often does not have any substantive interpretation. It is used only to simplify the specification of the model S'. This can sometimes lead to confusion if the models are to be used for policy analysis and design. This point will be discussed below.

§ 4 Control Systems as Models for Policy Evaluation

The discussions to this point have dealt mainly with the problems of developing descriptive theories and models, that is theories and models which account for observations in the empirical world and identify interrelationships. It is reasonable to assume that policy analysis and synthesis cannot proceed without valid descriptive models. In fact it is often necessary to develop more detailed and structured models consistent with descriptive theories before policy design can be attempted.

The use of control systems and adaptive systems in structures has often been suggested for policy oriented theory development (e.g., see the papers in Rosenau, 1974).

It is important at this point to distinguish between control systems and control problems. Control systems are systems with a particular structure. They are dynamic (parameterized by time), and have input objects that can be partitioned into at least two classes, manipulable inputs and disturbance inputs, i.e., $X=M\times W$ where M denotes manipulable inputs, W denotes disturbance inputs. The system is therefore modeled by

$$S \subseteq M\times W\times Y$$

and each object is a time object (set of time functions). The system has internal mechanisms for determining values for the manipulated variables at each point in time. The mechanism presumably enables the system to achieve desirable configurations and satisfactory overall performance.

A control problem on the other hand is a problem statement that need not have any relationship with a "real" system. Generally, a control problem consists of a system model

$$S_m : Z_m \times M_m \times W_m \to Y_m$$

and performance specifications consisting of the following triple; a performance function

$$P: S_m \to V$$

a tolerance function

$$T:\ W_m \to V$$

and satisficing relation

$$R \subseteq V \times V$$

The terminology is that of Mesarovic (1970). The control problem is considered solved if there is an element in m, say m_s, such that for all elements $z \epsilon Z_m' \subseteq Z_m$ and $w \epsilon W_m' \subseteq W_m$

$$(P\ (z, m_s, w, y),\ T(w)\ )\ \epsilon\ R$$

That is satisfactory performance is achieved for the disturbance set specified assuming the model S_m.

In almost all cases S_m is a constructively specified model and W, M and V are sets with a great deal of mathematical structure. The highly popular optimal control problems require that R be a partial order and T define the *minimum (or maximum) element in* V *for each element in* W_m. Essentially then the solution of a control problem is a constructive specification of a model. Whether or not this model is useful for policy analysis depends on the validity of S_m and the interpretations of the performance measures. Such utility is not guaranteed simply because the model derivation followed from a control problem formulation. That is, what is true of S_m need not be true of S unless S and S_m stand in some "known" relation to one another.

For the results to be useful the model S_m must in fact be a good representation of the system S. This most certainly requires that the disturbance set model W_m adequately represent W and not be the result of mathematical convenience. It also requires that predictions made with S_m be in some well defined sense be empirically correct. This fact is clearly recognized by the leaders in the development of optimal control theory, Athans (1971).

Brito (1972) uses an optimal control formulation in his derivation of an arms race model. His overall system involves two nations each of which

is modeled in terms of the above structure. Specifically, the following structure is used.

Nation one is modeled by

$$S_{m_1}: \; W_1 \times C_1 \times Y_1 \to W_1$$
$$P_1 : \; C_1 \times W_1 \times W_2 \to R$$

and nation two is modeled by

$$S_{m_2}: \; W_2 \times C_2 \times Y_2 \to W_2$$
$$P_2 : \; C_2 \times W_1 \times W_2 \to R$$

All of the objects are sets of non-negative real valued time functions and time is modeled by the non-negative reals. Specifically, for each nation

$$S_{m_i}: \{(W_i,\; C_i,\; Y_i) \mid \dot{W}_i(t) = Y_i(t) - C_i(t) - B_i W_i(t),\; o \leq t < \infty\}$$

and

$$P_i = \{(W_1, W_2, C_i, P_i) \mid P_i = \int_o^\infty e^{-r\,t}(U_1(C_i, D_i(W_1, W_2))\,dt$$

for some real number r, and functions U_i and D_i}

The utility function U_i is not specified but is assumed to have the following properties:

$$\frac{\partial U_i}{\partial C_i}\,[0,\; D_i(W_1, W_2)] = \infty \qquad W_1, W_2$$

$$\frac{\partial U_i}{\partial D_i}\,[C_i, D_i(0,0)] = K < \infty \quad C_i$$

$$\frac{\partial^2 U_i}{\partial C_i \partial D_i} \geq \quad 0 \qquad C_i, W_1, W_2$$

Also, the functions D_i are assumed to have the following properties:

$$\frac{\partial D_i}{\partial W_i} \geq 0$$

$$\frac{\partial D_i}{\partial W_j} \leq 0$$

$$\frac{\partial^2 D_i}{\partial W_i^2} \leq 0$$

$$\frac{\partial^2 D_i}{\partial W_j \partial W_j} \geq 0$$

In Brito's formulation C models the consumption level, W weapons stock levels, Y net national product levels. The weapons stock of nation i is the state and output of system i. The manipulated variable in system i is consumption level. The net national product of nation i is an external input to system i and can be considered the input. The weapon level of nation j is an external input and is a disturbance in system i.

Each control problem leads to a constructive specification for each system. That is, a set of solutions can be generated given utility functions and inputs. Specifically, the specification of system 1 is of the form

$$\begin{aligned} S_1' = \{ &(Y_1, C_1^*, W_1^*) \varepsilon S_{m_1} \mid \\ &P_1(W_1^*, W_2, C_1^*) \geq P_1(W_1, W_2, C_1), \\ &(W_1, Y_1, C_1) \varepsilon S_{m_1} \text{ and } W_2 \text{ specified} \} \end{aligned}$$

A similar construction holds for system two. Essentially, the specification consists of solutions to the control problem under the assumption that information about the disturbance (other nations weapons stocks) is given.

Brito is interested only in weapons stocks so the overall constructive specification of his system is

$$S' = \{ (W_1, W_2) \mid (Y_1, C_1, W_1) \varepsilon S_1' \;\&\; (Y_2, C_2, W_2) \varepsilon S_2' \}$$

It is clear from the above development that the functions which finally appear in the model S' are strongly dependent on the form of the individual system models and the structure of the performance measures. The only justification given for the model is that it is in fact optimal with respect to stated measures of performance and equations of motion. The class of functions defined by S' is broad, but as we will show later it is not necessarily representative of any "real" or even reasonable arms race system.

No control engineer would implement a control law (policy) without first verifying that it does in fact produce satisfactory performance. Typically

this is accomplished through testing on a prototype system or when this is not possible through test on a more detailed and more complete model than the model used to design the control law.

In particular, optimality does not imply that the control law is usable. Optimality is always a property of the model but not necessarily of the controlled system. This is why optimal control is useful for space flights where disturbances are minimal and system dynamics well understood but less useful for process control applications where the system dynamics and disturbances are less well understood. In fact, it is no exaggeration to say that no discrete state control system was ever designed with the methods of optimal control theory.

§ 5 Implications

Brito (1972) claims that his model of the arms race provides "an effective framework in which critical policy issues can be explored." He further claims his model proves that "...although the Strategic Arms Limitation Talks may succeed in reaching an agreement to maintain the status quo, neither side will agree to reduce arms levels." These are very strong claims based on a model, in fact on a constructive specification of a model, which is based on very tenuous substantive assumptions.

It is more accurate to state that Brito observed no pairs $(W_1,W_2)\epsilon S'$, where S' is the constructive specification of his theory, that decreased with time. Clearly, this observation about S' does not imply the same is true in some empirical system modeled by S. In fact no system S is established. It is safe to say that nearly all, if not all, of the statements in the theory are included for the constructive specification process and are not based on observed characteristics of real arms races. For example, the conclusion about non-decreasing weapons stocks is dependent directly upon assumptions about the utility functions involved and these assumptions are at best ad hoc.

It is enlightening to look carefully at some of the requirements of the Brito theory. For mathematical reasons only, "smooth" utility functions are used and marginal utility with respect to weapons is parameterized in the following way,

$$\frac{\partial U_i(C_i,D_i(W_1,W_2)}{\partial W_i} = \frac{\partial U_i}{\partial D_i}\frac{\partial D_i}{\partial W_i}$$

Various assumptions are made about the given partial derivaties and this has some interesting consequences.

Assume that nation one has the following utility function

$$U_1(C_1,D_1(W_1,W_2)) = \ln(C_1) + D(W_1,W_2)$$

with

$$D = (W_1-W_2)^2$$

The utility function is therefore

$$U_1(C_1,W_1,W_2) = \ln(C_1) + (W_1-W_2)^2$$

This utility function is not allowed by the Brito theory because

$$\frac{\partial^2 D_i}{\partial W_1^2} = 1 > 0$$

and the theory require that this partial derivative be non-positive.

Now, consider the utility function

$$U_1'(C_1, D_1(W_1, W_2)) = \ln(C_1) + D^2(W_1, W_2)$$

$$\text{where } D = W_1 - W_2$$

Clearly,

$$U_1'(C_1,D_1(W_1,W_2)) = \ln(C_1) + (W_1-W_2)^2$$

which is identically the same as U_1 defined above. U_1' is allowable under the Brito theory. All derivative conditions on U are met and

$$\frac{\partial D_1}{\partial W_1} = 1 > 0$$

$$\frac{\partial D_1}{\partial W_2} = -1 < 0$$

$$\frac{\partial D_1}{\partial W_1^2} = 0 \leq 0$$

$$\frac{\partial^2 D}{\partial W_2 \partial W_2} = 0 \geq 0$$

Hence we have one utility function which is accepted by theory under one specification but not another. One would expect an economic theory to be concerned about the utility function but one certainly would not expect

the theory to distinguish between alternate writings of the same function. The theory is clearly dependent on the specification and in fact is designed to meet the analytical needs of a particular model. The theory is not internally consistent. Brito's desire to "discriminate between these apparently conflicting viewpoints" of arms race stability is certainly not aided by a theory that cannot recognize the same utility function in two logically equivalent forms.

Claims about policy relevance certainly are not justified. We have been given a new theory and a new model was constructed but this model has no substantive content. We are treated to an exercise in mathematics, not policy analysis.

The sentences in the Brito theory have been shown to have highly implausible deductive consequences. That is, two logically equivalent forms of the utility function are treated differently within the theory. Thus, as a theory of arms races (i.e., of a referent reality consisting in part of weapons stocks, etc.) the Brito theory appears to be unsatisfactory. However it may be that the structure itself, S', is still useful and that the theory simply is an inaccurate description of the properties of S'. To show that this is not the case requires a different form of argument.

Recall that the structure considered by Brito consists of objects such as nations, each nation's stock of weapons and consumer goods, money and of relations such as reaction equations and utility functions for each nation. The question at hand is the extent to which these objects and relations correspond to those of the referent reality in which arms races are believed to take place. The point is not that a model must reproduce all of "reality." Such a position is clearly absurd since such a model would be no less tractable than "reality." However, to deny that models need replicate reality is not to say that any set of objects and relations is acceptable. As Samuelson

(1962) points out in a related context, "If the abstract models contain empirical falsities, we must jettison the models, not gloss over their inadequacies." Similarly, a putative model for a theory of arms races must not ignore without reason objects and relations which appear to be an important aspect of the referent reality. A partial (non-ordered) list of such aspects would probably include time variant utility functions (e.g., in periods of war), arms transfers, disturbance terms, observability problems, differences between decisions to build a particular level of arms and arms actually produced, non homogeniety of weapons systems with regard to threat, cost, deployment, lead time, "depreciation rate," etc., technological innovation, requirements for a nation to consider more than one nation's level of armaments in setting its own, selective targeting, and on and on. None of these seem to be expressible purely in terms of the objects and relations considered by Brito. The purpose of this list is not to suggest that we cannot usefully model arms races. Rather the argument of this paper has been that the modeling approach employed and the interpretation given to any results must be governed by substantive not mathematical concerns. Thus we have shown optimal solutions to be very "brittle" in the sense that their existence and stability is directly tied to the form of the equations used in writing the theory. If the form is chosen for mathematical rather than substantive reasons, then there is no reason to expect that policies which are optimal in S' will also be optimal or even "desirable" in S (especially when S is left unspecified). We simply do not know enough about arms races to embark upon an armaments policy which is based, for instance, upon the difference between differentiable and non differentiable utility functions.

In summary, mathematics provides a wide array of tools which are extremely valuable to international politics theorists both in the area of model specifi-

cation and in theory development. However, it is important that the specific mathematical tools chosen be chosen for substantive rather than purely mathematical reasons. This is not to say that substantive theory building cannot be greatly aided by having some people posing and solving analytic puzzles which provide insight into various "basic" principles. The recent history of psychology and economics suggests that the posing of such puzzles can be of considerable aid to theory development. However, and this is the point of our paper, such puzzles must not be confused with models for substantive theories. Unfortunately, it may be that as incentives for "policy relevance" increase, the temptation to confuse analytic puzzles with substantive models will become almost irresistable. Yet, as we have shown, much of the power of mathematical argument comes from its ability to identify "non-obvious" implications from explicit assumptions. Many mathematical results - and, in general, solutions to optimization problems - are extremely sensitive to the statement of assumptions. If there is no reason to prefer the precise statement to others which appear "roughly the same" but which do not all permit the existence of an optimum then we should be very cautious about our interpretation of "optimal solutions" in a policy context.

It is not sufficient that mathematical models are valid in the sense that they contain no errors in derivation. They must also be correct in that they be asserted to describe some "real" system. It should serve as a challenge to those who wish to use analytic mathematical structures in policy related problems to develop more robust models and provide explicit ties with substantive models.

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Production Systems as Models of Control
Structures for Governmental Decision-Making*

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§ 1 INTRODUCTION

Allen Newell (1973a, 290) has observed that there is a common view that "science advances by playing twenty questions with nature. The proper tactic is to frame a general question, hopefully binary, that can be attacked experimentally. Having settled that bits-worth, one can proceed to the next. The policy appears optimal - one never risks much, there is feedback from nature at every step and progress is inevitable. Unfortunately, the questions never seem to be really answered, the strategy does not seem to work." As an alternative Newell suggests developing explicit "complete processing models" of control structures (what we mean by "control structure" will be discussed in § 3,4) capable of exhibiting goal seeking behavior in fairly broad range of task environments. While the particular substantive domain Newell was writing about was experimental psychology, his comments are equally applicable to the field of international politics. Much of the research in international politics is centered around such binary issues as big-small, open-closed, stabilizing-destabilizing, domestic-international, center-periphery and so on. Unfortunately research on these and other binary oppositions has not so far resulted in the sort of general theory of national behavior that many of us would like to see. Perhaps, as is sometimes argued, it is still too early and we must continue rather narrow gauge exercises for a while longer before expecting theoretical payoff - we must move slowly from the simple to the more complex.

However, there are several problems with the "simple to the complex" view. First, the terms "simple" and "complex" are themselves relative to a particular description and it may be that "simple" descriptions of anything as "complex" as the way governments process information to produce behaviors will simply be useless or misleading. Indeed this logical possibility was suggested by Von Neumann (1966,) when he wrote: "There is a good deal in formal logics

to indicate that the description of an automaton is simpler than the automaton itself as long as the automaton is not very complicated, but that when you get to high complications, the actual object is simpler than the literary description." In other words, models of governmental control structures may be simpler to construct and exhibit than to describe. If such is the case computer simulation becomes a useful tool.

A second problem with the "simple to complex" position is that it fails to recognize that the simple is interesting only in the context of some (perhaps veiled) picture of the complex. Without a comprehensive view we run the danger of retracing the steps of Sommerhoff's spy who was so obsessed with detail that he followed the telephone cables of the Pentagon to uncover the "true" source of power - and located the Pentagon telephone exchange.

The purpose of this paper is to use a preliminary attempt to model Saudi Arabian decision making to illustrate how control concepts can be useful in developing complete processing models of governments. The Saudi government is viewed as an information processing system. Such systems can be described generally in terms of 1) the goals of the processor 2) the structure of the processor 3) the structure of the outer environment (or specific task environments). The structure of the processor will be modeled by a scheme known as production systems (see § 7). One difference between the approach presented in this paper and most other uses of control theory in international relations is our concern with modeling the internal structure of the processor. While formal reasons for this concern are presented in § 7, a frequently encountered example might serve to illustrate the sense in which we are interested in internal structure.

As a final exam an electrical engineering class is given a sealed black box with three input terminals and two output terminals together with a catalog of electrical components. The exam task is discover the internal "wiring" of the box by observing its behaviors as functions of changes in input signals

(probably in the form of electrical impulses). Specifically, they must draw a schematic diagram of the black box mechanism which is complete enough to allow a replica to be built.

To solve the problem, a student must analyze input-output relations to come up with possible mapping functions. However, an input-output analysis is not enough. He must also synthesize and build a mechanism which can actually perform the mappings identified in the analysis. That is, he must model a structure which processes inputs in such a way as to produce the observed outputs. Clearly, not only will any "blueprint" for the mechanism be non-unique, but so will any specification of procedures for moving from the blueprint to an operating realization of the mechanism. Yet, these additional considerations will be of interest to the student of international politics. This process of modeling internal structure might be termed mechanism elucidation (after Fedorov, 1972). It is in this sense that input-output analysis is not enough.

The black box example is, we believe, analogous to the problem of developing theories of the behaviors of governments. Again we must be concerned with the structure which processes information as well as the input-output relations which obtain. Moreover, while we have no "catalog of components" to aid in structural specification, there are a number of observations which, taken together, greatly limit the class of admissible structures. These characteristics of governments will be outlined in the next section.

§ 2 STRUCTURAL CHARACTERISTICS

In modeling governments there appear to be several structural characteristics which any potential complete processing model of a government should exhibit. While each of these principles is fairly simple, taken together there are few existing models which simultaneously satisfy all of them. In this section these principles will be briefly introduced. Succeeding sections will then discuss how control structures might be identified which satisfy them.

First, governments attempt to manipulate specific external environments and therefore if the government is modeled as a control structure, explicit attention must also be paid to modeling the range of environments in which the government operates. Modeling the government as a control structure in no way entails treating it as an optimal controller. A well known attempt to model international behaviors without treating governments as control structures is found in Forrester (1971). In constructing the models of governmental control structures and their environments it is important to explicitly allow for disturbances. The importance of disturbances in the international environment receives implicit support from the ongoing concern over such issues as "accidental way." Disturbances play important roles even in such relatively sophisticated devices as military communications channels. Iklé (1973) cites the example of the Joint Chiefs decision at the beginning of the Six-Day War to order the U.S. ship Liberty into less dangerous waters. The order was sent in at least four different messages over the 13 hour period prior to the Israeli attack. None of the messages was received in time by the Liberty. Two of the messages were misrouted, a third was lost in a relay station, and a fourth was delayed until hours after the attack. "The failure in emergency communications occurred under almost perfect conditions: No

facilities had been disabled, there was no enemy jamming and no restrictions on the use of available communication modes (273)." Attempts must be made to model such disturbances.

Second, the internal structure of the government should be modeled. That is, useful models of governments must go beyond preserving input-output relationships to also characterizing the manner in which input information is transformed into outputs. There is considerable evidence to suggest that such an approach requires at least modeling bureaucratic structures within governments (e.g., see Allison, 1971; Halperin, 1974). Such an approach is distinct from, for example, the "unitary rational actor" perspective adopted by most of the arms race modelers. Furthermore, bureaucracies within governments are organized hierarchically. There is considerable specialization within governments and different information and decisions are processed at different points in the hierarchy. This suggests that the control structure will, in some sense, be modeled by a multi-level controller. Further support for this claim can be found in Phillips (1974); Anderson (1974); and Nurmi (1974).

Third, governments pursue multiple (and sometimes conflicting) goals. For example, with respect to the decision to cancel the Skybolt air-to-ground missile, Halperin and Kanter (1973,402) point out "each actor had a different problem and pursued varying objectives." The report on Skybolt by Brandon (1973) suggests that a consideration of these different objectives within both U.S. and U.K. would be required in any descriptive policy study. From a mathematical control perspective, the multiple goals issue poses interesting technical and philosophical issues and §5 is devoted to a discussion of them.

Fourth, governments exhibit redundancy of potential control. According to Arbib (1972, p. 17) the principle of redundancy of potential control "states,

essentially, that command should pass to the region with the most important information." As an illustration Arbib (who attributes the example to Warren McCulloch) cites "a World War I naval fleet where the behavior of the whole fleet is controlled (at least temporarily) by the signals from whichever ship first sights the enemy, the point being that this ship need not be the flagship, in which command normally resides (p. 17)." The critical point here is that potential control need not reside in only one portion of a government. Indeed the way in which various governments resolve the redundancy is critical to understanding and explaining its behavior. Current attempts by the U.S. military to upgrade its command, control, and communications "systems" reflects an implicit recognition of the redundancy notion within one bureaucracy. Moreover, important decisions (e.g., whether to sell a sophisticated weapons system to some country) generally involve more than one bureaucracy at more than one level of the hierarchy.

Fifth, governments are event-based (that is, governments respond to events in the external environment). These events may have associated with them particular probability distributions. Moreover, the notion of time employed in the model should be "event time," that is, the "time flow" against which the system states are plotted should be event based. This suggests, for example, that differential equation models are either inappropriate or require considerable reinterpretation. The arms race models and the Forrester model are inconsistent with this principle. Crecine (1969) provides evidence for the event-based nature of governmental structures. The implications of this for specifying time sets in formal control problems are discussed below.

The structural properties just outlined are serving as framework conditions as we attempt to elucidate the mechanisms through which governments process information by modeling to Saudi Arabian decision making with respect to a

variety of domestic policy areas. A computer simulation approach has been adopted. The present preliminary version of the Saudi simulation is divided into three external environment modules: an agricultural module, an oil module, and a human resources module. A fourth module, the decision module, serves as a model of the governmental control structure. While our central interest is in modeling the control structure, the first principle mentioned above requires that some attention be paid to modeling the external environment. These simulations are being developed in interaction with policy planners in the U.S. State and Defense Departments (see Phillips and Thorson, 1974, for a description of the interaction). In this paper the focus will be on that portion of the decision module attempting to "control" the agriculture module. However, before getting into a discussion of the specific simulation, it is necessary to state more precisely the claims which have been made thus far and to show how such claims entail a different view of control problems than that generally encountered in international politics.

§ 3 FORMAL MODELS OF CONTROL SYSTEMS

It has been argued that governments can be viewed as control structures operating in specific environments. In this section an abstract formal description of control systems is presented and several structural properties of control systems are detailed. This structure provides the background necessary to distinguish between control systems and control problems and will be used later in the paper to relate production systems and control systems.

Control systems are systems with particular structure. The structure is graphically represented in Figure 1. The basic elements are 1) the inner environment or government or controller; 2) an access interface; 3) the outer environment or the controlled process; 4) an observation interface. Formally the system can be described as an abstract system as follows:

$$S \subseteq IE \times AI \times OE \times OI$$

The system then is a set theoretic relation on the inner environment, the access interface, the outer environment, and the observation interface. Each of these is also an abstract system:

$$IE \subseteq Y \times U$$

$$AI \subseteq U \times M$$

$$OE \subseteq M \times X$$

$$OI \subseteq X \times Y$$

where Y, U, M, X denote the set of possible observations, the set of manipulated inputs or controls, the set of implemented controls, and the set of outer environment responses respectively. Furthermore, the system is dynamic (parameterized by time) which means that the system objects are sets of time functions, i.e.,

$$Y \subseteq A^T$$

$$U \subseteq B^T$$

$$M \subseteq C^T$$

$$X \subseteq D^T$$

where T is a time set and A, B, C, D are the alphabets or sets of possible values for the respective system objects. The superscript notation is used to represent the set of all time functions, e.g.

$$A^T = \{y \mid y: T \rightarrow A\}$$

The alphabets are arbitrary and finite cardinality is possible but not necessary. The time set T is assumed to be, following Windeknecht (1971), an ordered commutative monoid.

The system is further structured by the requirement that it be closed in the sense that

$$s = (y_1, u_1, u_2, m_1, m_2, x_1, x_2, y_2) \in S \leftrightarrow$$

$$y_1 = y_2; \quad u_1 = u_2; \quad m_1 = m_2; \quad x_1 = x_2$$

This does not imply that each subsystem is functional (i.e., a mathematical function) but simply requires that the outputs of each subsystem are the inputs of the next.

For purposes of analysis it is customary to place the observation and access interfaces together with either the inner or outer environment. That is, the system can be modeled by

$$\bar{S} \subseteq IE \times \bar{OE}$$

where

$$\bar{OE} = OI \circ (OE \circ AI)$$

where $\circ$ denotes the composition of relations. This in general causes no confusion but some caution must be taken to insure that given data are associated with the appropriate system objects.

In modeling and theorizing about governments the primary object of analysis is the inner environment IE,

$$IE \subseteq Y \times U$$

(or some composition involving the inner environment and the observation and access interfaces.) At this level of abstraction the government is modeled by an ordered

pair of time functions, which serve to establish the objects of interest but which cannot provide much descriptive or prescriptive information. If one could be certain that governments were time invariant in an intuitive sense and that off line experiments could be performed to identify the model, such a model might provide such information.

Nevertheless, certain additional properties must be accounted for even at this level of abstraction. The most important property is that the IE subsystem must be a non-anticipatory processor (more precisely a state determined transitional processor, Windeknecht, 1971). Specifically, the inner environment must be decomposible into the composition of a static system and a transitional system,

$$IE = \Phi \circ \Gamma$$

$$\Gamma \subseteq Y \times Z$$

$$\Phi \subseteq Z \times U \quad , \quad Z = E^T$$

for some set E, the state object of OE. Φ must be a static processor (system) which means that for each $t \in T$ the set

$$t\Phi = \{(z(t), u(t)) \in E{\times}B \mid (z,u) \in \Phi\}$$

is a function. Γ is required to be transitional, i.e., the set

$$tr\Gamma = \{(((y_t)^{t'}, z(t)), z(t+t')) \mid (y,z) \in \Gamma \wedge t, t' \in T\}$$

must be a function. $(y_t)^{t'}$ denotes an element in $Y|[t, t+t')$ which is the set of inputs restricted to $[t, t+t')$.

The function $tr\Gamma$ is the state transition function for IE and $t\Phi$ is the output function. These functions are auxilliary functions which can be used to constructively specify the inner environment. In particular this structure guarantees that every output value depends only on previous inputs and the system state.

The representation used above is that of a very general dynamical system. In terms of substantive descriptive modeling issues, the formulation clearly shows the need for identifying the state object, the state transition functions and out-

put functions of the government or inner environment. The emphasis is on the mechanism or process by which inputs from the observation interface are converted to responses and not on the characteristics of these inputs and outputs per se. Clearly however, given the internal structure of the processor, outputs can be generated given inputs, or in other words, if the detailed structure of the system is known its behavior can be predicted. The method by which these structures are to be identified is not established by the abstract structure, but the need for such identification is clearly established.

In summary then, governments are dynamic mechanisms which are presumably "goal-seeking." Goals will provide one way in which the internal structure of the inner environment can be specified. Before examining this issue in greater detail, the technicalities of control problems and goals for control systems will be examined.

§ 4 CONTROL PROBLEMS, OPTIMAL AND SATISFACTORY

The basic structure of the inner environment or controller of a control system was presented in the previous section. There are clearly an infinity of mechanisms that could serve as controllers and which meet the structural requirements. The choice of one mechanism over another depends on the objectives or goals that the system is to achieve. In this section goals are formally modeled with performance measures and other related mathematical apparatus and relationships between mechanism and goals are obtained. Optimal control problems are examined first followed by satisfactory performance problems and multiple goal problems.

Optimal Control Problems

All control problems require additional abstraction beyond that of the general control system model presented in the previous section. Here, an image or model of the external environment (controlled process) is needed. To simplify the development somewhat the access and observation interfaces are composed with the outer environment and the model describes the overall u to y response. In addition, it is convenient in control problems to posit exogenous but non-manipulated inputs or disturbances which influence system behavior. Specifically,

$$OE_m \subseteq U_m \times W_m \times Y_m$$

$$U_m = B_m^{T_1}$$
$$W_m = F_m^{T_1}$$
$$Y_m = A_m^{T_1}$$

A_m, B_m, F_m are model alphabets and T_1 is the model time set. The disturbance set W_m may have physical interpretations as it does in process control applications or it may simply represent model uncertainty, i.e., a mathematical object used to account for deviations between observations and model appearances. The other piece of apparatus needed for an optimal control problem is a performance function

$$P: OE_m \to V$$

where V is a value set partially ordered by some relation denoted here by $\leq$. The performance function evaluates appearances of the model and presumably allows one to pick a best input assuming one exists.

Without loss of generality it can be assumed that OE_m is constructively specified with state transition and output functions. Specifically, assume that

$$OE_m = \Psi o \Omega$$

$$\Psi \subseteq Q_m \times Y_m \quad , \quad Q_m = G^{T_1}$$

$$\Omega \subseteq U_m \times W_m \times Q_m$$

Ψ is static and Ω transitional which implies that for each $t \epsilon T_1$ the set

$$t\Psi = \{(q(t), y(t)) \ \epsilon \ G \times A_m \mid (q,y) \ \epsilon \ \Psi\}$$

is a function and the set

$$tr\Omega = \{(((u_t)^{t'}, (w_t)^{t'}, q(t)), q(t+t')) \mid (u,w,q) \ \epsilon \ \Omega \wedge t,t' \ \epsilon \ T_1\}$$

is also a function. With these functions it is possible to write the model output as a function of the initial state and intervening inputs. For any $t \epsilon T_1$

$$y(t) = t\Psi \ (q(t))$$

$$= t\Psi \ (tr\Omega \ (\ (u_o)^t, \ (w_o)^t, \ q(o)))$$

The initial time or least element in T_1 is denoted by o. Notice that the initial state may play the same role as a disturbance. Also, if desired it is possible to represent the disturbance as a state determined system but there is little point in doing so here.

The structure of the optimal control problem can now be discussed. An optimal control will in general depend on the specific disturbance input and initial state. Corresponding to each disturbance input, initial state pair consider the set

$$q_o w U^* = \{u^* \epsilon U_m \mid (u^*, w, y^*) \ \epsilon \ OE_m \wedge$$

$$P(u^*, w, y^*) \leq P(u, w, y) \ \forall \ u \epsilon U_m \wedge \forall$$

$$t \epsilon T_1 \quad y^*(t) = t\Psi(tr\Omega((u_o^*)^t, (w_o)^t, q(o)))\}$$

This set is the set of controls which are optimal under the performance function

P for the given disturbance, initial state pair. Clearly, the set $q_o wU^*$ is empty if no optimal solution exists.

As pointed out above there is typically a distinct set of optimal controls for each disturbance input. In most problems of practical interest the control designer must specify a class of disturbances and initial states for which the system is to operate optimally. Label this set $\hat{W}_m$, $\hat{W}_m \subseteq W_m \times G$ and assume that for each element $(w,q_o)\varepsilon\hat{W}$ the set $q_o wU^*$ is obtained. These sets can be used to form a relation which provides the possible optimal controls given the disturbances. That is, the relation

$$U^*=\{((q_o,w),u^*)\ \varepsilon\ \hat{W}_m \times U_m \mid u^*\varepsilon q_o wU^*\}$$

associates a set of controls with each disturbance initial state pair.

Some very important and general observations can be made based on the above description of the optimal control problem solution. First, the solutions are time functions, $u^*\varepsilon U_m = B_m^{T_1}$. Second, obtaining such solutions generally requires clairvoyance since controls are paired with disturbances (which are in general also time functions) by the relation U^*. Third, optimality is judged by the outer environment model OE_m and not by the outer environment itself. Unless there is some guarantee that OE_m is in some sense a valid model, optimality is a useless property (see Miller and Thorson, 1975).

Under certain circumstances, i.e., certain disturbance classes and performance measures, the clairvoyance difficulties may not be so severe. For example, there exists an open loop control $u^*\varepsilon U_m$ which solves the optimal control problem for <u>all</u> disturbance, initial state pairs if and only if

$$\cap\{q_o wU^*\} \neq \phi$$

This requires that controls be in some sense independent of the disturbances. Similar conditions can be obtained for certain disturbances with which the optimal control is only a function of the initial state. Clearly, for problems of any substantive interest open loop controls typically will not exist for rich disturbance classes.

Satisfactory Control

Some of the difficulties can be eliminated with the notion of satisfactory performance as proposed by Simon, 1957. A modification of the formalization of Mesarovic, et al, 1970, is used here. Basically, the problem structure is the same as above but a tolerance function and satisfaction relation are included. Particularly,

$$T\colon\ W_m \times G \rightarrow V$$

$$SR \subseteq V \times V$$

Performance is deemed satisfactory if with a control u, given disturbance w, and initial state q_o

$$(P(u,w,y),\ T(w,q_o)) \in SR$$

Notice that V does not have to be ordered to use the satisfaction relation. Typically however V would be ordered by the relation $\leq$ used in the optimization problem. The satisfaction would then define a minimum (or maximum) level so that performance would be deemed acceptable if

$$P(u,w,y) \leq T(w,q_o)$$

For a given performance function, tolerance function and satisficing relation the control problem solution can be expressed in much the same manner as for the optimal control problem. For each element $(w,q_o) \in \hat{W}_m \subseteq W_m \times G$ define the set

$$\begin{aligned} q_o wU = \{u \in U_m \mid\ & (u,w,y) \in OE_m \\ & \wedge (P(u,w,y),\ T(q_o,w)) \in SR \wedge \\ & \forall t \in T_1\ \ y(t) = t\forall(tr\ \Omega\ ((u_o)^t,\ (w_o)^t,\ q(o)))\} \end{aligned}$$

The definition is very similar to that used for the optimal control, but presumably the tolerance function and satisfaction relation are such that controls are easier to come by. In particular, the tolerance function and satisfaction relation reduce the severity of the clairvoyance problem.

It must be pointed out however that the satisfaction problem as posed here

still results in a relation pairing disturbances and controls, i.e., the sets $q_o wU$ can be used to construct the relation

$$U^s = \{((q_o, w), u) \quad \varepsilon W_m \times U_m \mid u \varepsilon q_o wU\}$$

Selection of a control requires knowledge of initial state and disturbance, but presumably a given control solves the control problem for a class of disturbances.

Tolerance functions and satisficing relations are often introduced implicitly. For example, if design is based on a "typical" disturbance $\bar{w}$, a control which optimizes performance for this disturbance is found. Optimal performance will not necessarily be achieved for other disturbances and a range of performance is possible depending on the possible disturbances. This range essentially defines the satisficing relation in $V \times V$.

The same is true of probabilistic methods. If a control is selected to minimize the expected performance, a range of performance is again possible depending on disturbances. A design which determines a control to keep the performance value within a specified region with some probability is explicitly using a tolerance - satisfaction approach.

The basic problem with both the optimal control and satisfactory control results of this section is their structure. They are time functions and not processors or systems. This resulted because of the structure of the control problem formulation. In section §6 the realization problem and duality between mechanism and goal is examined. This will provide the tie between the descriptive results of the previous section and the control problem results of this section. First, the problem of multiple goals is briefly considered.

§ 5 MULTIPLE GOALS

It is generally recognized that governments are multiple goal organizations but it is quite difficult to establish what this statement means in any but an intuitive way. In defining and modeling governments as control mechanisms however, it is important to have a precise formulation of what is meant by multiple goals. One such structure is provided in this section.

The same overall macro view of the outer environment of a government that was used in the previous section is again used here. The same state determined model of the outer environment that was used in the previous section is again assumed.

For purposes of discussion here, a multiple goal control problem is one in which there are several performance measures of interest for the system. That is, there are say k distinct functions which evaluate system performance:

$$P_i: OE_m \to V_i \qquad 1 \leq i \leq k$$

The value sets need not be identical. It is assumed however that for each i there is a relation R_i which partially orders V_i.

Two comments about this structure are in order. First, we do not assume the existence of an <u>explicit</u> aggregate performance function, i.e., a function (or even a class of functions) of the form

$$\bar{P}: P_1 \times P_2 \times \ldots . P_k \to \bar{V}$$

is not assumed. The reason for this assumption is that such an aggregate, single valued performance function reduces the problem to the single performance measure problem discussed in the previous section. It seems unreasonable to impose this additional structure at the outset although it perhaps is necessary for algorithm development. The second comment deals with the relationship between the structure of the process model and the structure of individual performance measures. The system model is multi dimensional involving control inputs, disturbances, and outputs or outcomes. The performance function is assumed to map <u>system</u> appearances,

as represented by the model, to some value set. Each performance function can therefore provide tradeoffs between the various system objects and each performance function represents one such trade-off evaluation. For purposes of discussion here, multiple goal situations refer to cases in which the designer or decision-maker or controller has several methods of evaluating performance.

Multiple goal or multiple objective problems have not received a great deal of attention in the control theory literature. The mathematical programming literature provides some results under the label of multiple objective programming and goal programming but these typically deal with ways of combining or aggregating individual measures (Cochrane and Zeleny, 1973). Some recent methods however allow significant interaction with the decision maker (Geoffrion et al, 1967). All of these results however deal with problems that have a great deal more mathematical structure than has been imposed here. Given that the issue is concept development it is undesirable to let such methods dictate problem formulation.

It seems that a more general and less constraining view of multiple goal than that provided by the mathematical programming literature is that provided by a generalization of the satisfaction notion of the previous section. Assume that corresponding to each performance function a tolerance function is also defined. That is,

$$T_i: \; W_m \times G \to V_i$$

A satisfaction relation is then a relation of the form

$$SR \subseteq V_1 \times V_1 \times V_2 \times V_2 \times \ldots \times V_k \times V_k$$

Given an appearance of the system model, $s=(u,w,y)$ corresponding to the disturbance w and some initial state q_o, the control u is satisfactory if

$$((P_1(s),T_1(w,q_o)), \; (P_2(s),T_2(w,q_o)), \; \ldots \; (P_R(s),T_R(w,q_o))) \in SR.$$

The problem is certainly more complex than a single goal problem, but certain features are unchanged. Satisfactory controls are still tied to disturbance func-

tions and initial states. The satisfaction relation essentially allows representation of the problem in terms of constraints. It is rich enough to include ordering or ranking of objective functions (through choice of individual tolerance functions), it includes as a special case situations in which certain performance functions are optimized (again through choice of individual tolerance functions). No method is provided for defining overall system performance and hence satisfactory solutions cannot be ranked except on individual performance dimensions.

The point of the discussion however is that with single or multiple goals, satisfaction or optimality, the control problems as posed always lead to a relation of the form

$$U^S = \{((q_o,w),u) \in \hat{W}_m \times U_m \mid u \epsilon q_o wU\}$$

where $q_o wU$ is the set of controls which achieve satisfactory performance given the initial state q_o and disturbance w. Multiple goals presumably increase the difficulty of the technical problem of finding solutions and satisfaction measures reduce somewhat the information requirements, but neither changes the basic mathematical structure of the solution. Also, this structure in its present form cannot be used to directly describe governments. Performance functions even with good outer environment models, do not lead directly to models of government. The reason, as will be shown in the next section, is very similar to the reason why solutions of optimal control problems do not necessarily lead to solutions of control system design problems.

§ 6 STATE DECOMPOSITION OF A CONTROL PROBLEM SOLUTION

The results of the previous two sections show that the solutions of control problems are mathematical relations establishing control trajectories in terms of disturbance trajectories. The problem of interest in this section is that of constructing a processor to realize the control inputs in a transitional manner using only available information. In the process relationships between performance requirements and mechanism or processor descriptions of the controller are developed.

The first step is to develop a model of the inner environment to realize the controls with respect to the model of the outer environment model. Recall that the satisfaction or optimal control problems provide, assuming solutions exist, a relation

$$U^S = \{((q_o,w),u) \in (G \times W_m) \times U_m \mid u \in q_o wU\}$$

That is corresponding to each initial state and disturbance there is at least one control which solves the control problem based on an outer environment model,

$$OE_m: \; G \times W_m \times U_m \to Y_m$$

This description of the outer environment model is an initial state representation which clearly follows from the state decomposition model used earlier.

From OE_m it follows that for each control $u \in U^S$ there is a corresponding outcome y. Therefore, appearances of OE_m using optimal or satisfactory controls can be written

$$OE_m^* = \{(q_o,w,u,y) \in G \times W_m \times U_m \times Y_m \mid (q_o,w,u) \in U^S \wedge (q_o,w,u,y) \in OE_m\}$$

OE_m^* is that subset of OE_m which results when non-satisfactory controls are excluded. A general processor model of the inner environment then follows immediately,

$$IE_m = \{(y,u) \in Y_m \times U_m \mid \exists \, (q_o,w): \; (q_o,w,u,y) \in OE_m^*\}$$

This model is the general dynamical system or processor which solves the control problem for the given outer environment model.

Results of Windeknecht (1971) are now used to provide a state decomposition of IE_m. Define

$$u_t = \{(\tau, u(t+\tau)) \mid \tau \epsilon T_1\}$$

and for each $u \epsilon IE_m^2$, where

$$IE_m^2 = \{u \mid (y,u) \epsilon IE_m\}$$

associate the set

$$\text{Fut } u = \{(t,u_t) \mid t \epsilon T_1\}$$

u_t is a left translation of the function u and is itself a time function. Fut u is the set of appearances of translation of the input u at all times $t \epsilon T_1$. A state decomposition of the inner environment is provided using these sets.

Let

$$\Gamma_m = \{(y,\text{Fut } u) \mid (y,u) \epsilon IE_m\}$$

$$\Phi_m = \{(\text{Fut } u, u) \mid u \epsilon IE_m^2\}$$

Clearly

$$IE_m = \Phi_m \circ \Gamma_m$$

The transition function of Γ_m is

$$tr\Gamma_m = \{(((y_t)^{t'},(\text{Fut } u)(t)),(\text{Fut } u)(t+t')) \mid (y,u) \epsilon IE_m \wedge t,t' \epsilon T_1\}$$

Careful examination will show that

$$(\text{Fut } u)(t) = u_t$$

That is, (Fut u)(t) is Fut u evaluated at t and is the left translation of u corresponding to time t. Therefore,

$$tr\Gamma_m = \{(((y_t)^{t'}, u_t), u_{t+t'}) \mid (y,u) \epsilon IE_m \wedge t,t' \epsilon T_1\}$$

To see that tr Γ_m is a function, assume that $(((y_t)^{t'}, u_t), u_{t+t'}) \epsilon$ tr Γ_m and

$$(((z_\tau)^{\tau'}, v_\tau), v_{\tau+\tau'}) \epsilon tr\Gamma_m$$

Then, if $(y_t)^{t'} = (z_\tau)^{\tau'}$ it follows that the time shift is the same. Thus, if $u_t = v_\tau$ then common time shift implies

$$(u_t)_{t'} = (v_\tau)_{\tau'} \rightarrow$$

$$u_{t+t'} = v_{\tau+\tau'}$$

which proves that tr Γ_m is a function.

Φ_m is a uniformly static function. That is, the attainable space of Φ_m is

$$\alpha\Phi_m = \{(Fut\ u)(t),\ u(t)) \mid u\epsilon IE_m^2 \wedge t\epsilon T_1\}$$
$$= \{(u_t, u(t)) \mid u\epsilon IE_m^2 \wedge t\epsilon T_1\}$$

$\alpha\Phi_m$ is a function since

$$(z_\tau,\ z(\tau))\ \epsilon\ \alpha\Phi_m$$
$$(u_t,\ u(t))\ \epsilon\ \alpha\Phi_m$$

and $z_\tau = u_t \rightarrow z_\tau(o) = u_t(o) \rightarrow z(\tau+o) = u(t+o) \rightarrow$

$z(\tau) = u(t)$.

The conclusion is that Γ_m and Φ_m provide a state decomposition of the inner environment model. Furthermore, the set

$$\overline{IE}_m^2 = \{u_t \mid u\epsilon IE_m^2 \wedge t\epsilon T_1\}$$

is a state space for the inner environment model, the set of initial states is IE_m^2 and the set of state trajectories is $\{Fut\ u \mid u\epsilon IE_m^2\} = \Gamma_m^2$

The above proves the existence of a state decomposition of the inner environment model. In practice it is not necessary to work with the above decomposition and a more convenient state representation can be obtained and used. The representation presented above is however the smallest (in the sense of the cardinality of the set of state trajectories) state decomposition that can be used. The interested reader is referred to Windeknecht (1971) for more details.

It is important to fully understand the significance of these results. In order to facilitate the discussion an equivalent state decomposition is used. Consider a one-one, onto function f,

$$f:\ \Gamma_m^2 \rightarrow z_m \quad ,\ z_m \subseteq E_m^{T_1}$$

and let

$$\gamma_m = \Gamma_m \circ f$$
$$\phi_m = \Phi_m \circ f^{-1}$$

Then, $\phi_m \subset Z_m \times U_m$

$\gamma_m \subset Y_m \times Z_m$

and $IE_m = \phi_m \circ \gamma_m$

Hence, ϕ_m and γ_m are another state decomposition of IE_m. This change does not alter the substance of the problem at all, but allows us to use labels or indices for the states.

The behavior of the state realized model of the inner environment can now be examined. Using the state decomposition it follows that for any time $t \epsilon T_1$,

$$u(t) = a\phi_m(tr((y_o)^t, z_o)$$

where $a\phi_m$ denotes the attainable set of ϕ_m,

$$a\phi_m = \{(z(t), u(t)) | (z, u) \epsilon \phi_m \wedge t \epsilon T_1\}$$

The function which defines u can be interpreted as a control law or policy. That is, it is a rule which is used to map information to all control actions. At present it is a policy which applies only to the model of the outer environment, not the outer environment itself.

This control law has some very interesting features however. First, it is designed to operate only as those elements of Y_m that are outputs in OE_m^*. It is entirely possible that there exist outputs in Y_m (corresponding to disturbances not considered) that cannot be processed by the controller, i.e., the state transitions are not defined for such inputs. Second, corresponding to each controller initial state is a family of control trajectories each member a function of the response obtained and hence dependent on the disturbance. The problem of how the controller gets into a particular initial state <u>is not</u> answered by the state decomposition method. The method simply says that <u>given</u> initial state and the observation trajectory, control trajectories can be computed. In a sense, one problem has been replaced by another. Selection of a control trajectory required

clairvoyance, initialization of the controller requires knowledge of the proper initial state and hence clairvoyance. That is, there is no apriori guarantee that performance is satisfactory if the controller starts in any but the correct initial state or set of states.

Fortunately, things are not as bad as they first seem although there can be difficulty if optimal performance is insisted upon. There is a wide class of problems which meet the conditions imposed - control engineers would be out of business otherwise. Satisfactory performance plays an important role here.

Static controllers is one class which does not have initial condition problems. With a static controller only the current observation value is needed to compute the control, i.e., the set

$$tIE_m = \{(y(t), u(t) | (y, u) \epsilon IE_m \wedge t \epsilon T_1\}$$

is a function. The state of the controller at time t is y(t) and the control is computed with tIE_m. The widely studied *linear-quadratic regulator problem* of optimal control theory falls in this class if complete state measurements are available (Athans & Falb, 1966).

Stochastic regulators and observers however do suffer from the problem in the sense that the controller initial conditions must be properly set for performance to be optimal (Bryson & Ho, 1969 ; Miller, 1973).

Satisfactory performance plays an important role at this point. Essentially, the role of the tolerance function and satisfaction relation is to enrich the set of acceptable controls in a control problem. If the set U^S is a relation and not a function, then the satisfactory control corresponding to a given disturbance is not unique. Recall that U^S was defined in the previous section and relates disturbances with acceptable controls. If U^S is in some sense large enough that all controller initial conditions produce control trajectories in output set of

U^S the problem is eliminated. One way to guarantee this is to restrict the problem to selecting mechanisms. That is, a class of controllers (state transition functions and controller output functions) are posited and the design objective is to select one of these mechanisms. This is precisely the procedure followed in most classical control theory and it is the way most control engineering work proceeds.

The view expressed above is the technical design view. Given that governments are operating systems, a more appropriate view is that of the evolution of the process or system. Loosely speaking this reflects a concern about what the system itself looks like at time t rather than a concern about the particular appearance of the system. The initial state issue is of less concern in this view and adaptation concepts take on an important role. This concept will not be pursued further in this paper.

The conclusion to be drawn from this section is clear. There is a very strong relationship between control problem solutions and the mechanisms which are used to realize control systems. The performance requirements reflected through performance functions, tolerance functions and satisfaction relations together with an outer environment model place constraints on acceptable controller behavior. These constraints are directly reflected in the state space and state decomposition used to represent the control mechanism.

§ 7 REALIZATIONS OF THE CONTROLLER VIA PRODUCTION SYSTEMS

The discussion of the previous section is concerned with the problem of constructively specifying the control mechanism at the level of the model or image of the outer environment. In a sense, the resulting system is the conceptual model of the way in which the controller is put together and functions. It is clearly defined in terms of the alphabets and time sets of the outer environment model and not those of the outer environment.

A control problem is not complete when a model can be controlled. The model mechanism must be mapped to a structure defined on the alphabets and time sets of the outer environment and this structure must be physically realized. Suffice it to say that the detailed structure of the implemented or realized controller always differs from the model structure and the controller must operate in an environment that is far more complex than the environment assumed for the control problem. Whereas mathematical convenience might dictate the choice of model alphabets, time sets and relations, it cannot dictate the realization.

Ideally there exists function preserving morphisms (and therefore behavior preserving morphisms) in the sense of Zeigler (1970) between the realized control system and the model. There need not however be structure preserving morphisms in the strict sense. That is, the precise way in which the controller is constructed and operates is not generally of concern in the control problem - controller realization activity. Certain kinds of state transition functions, output functions and associated trappings are required, but the precise manner in which these operations are actually performed is not of concern. Detailed structure is not necessarily preserved (and generally is not preserved). For example, a control engineer probably does not care if a digital computer or an analog computer is used to implement a process control system as long as

the desired control behavior is achieved and control function carried out. The detailed structure of the two control systems so realized would however clearly be different.

The implication for modeling governments is clear. The control problem formulation can be used to provide a state decomposition of the government model which is at best functionally equivalent to the government operation. Precisely, state decomposed set theoretic model discussed in section §6 , can be mapped to the controller model IE_m. This model does not, however, describe how the government goes about producing the state transitions. It simply says that they do make such transitions.

Moreover, as was mentioned above, in order for a government to respond adaptively to the O.E., it is essential that it have some sort of image or model of the O.E. The concept "image" here is being used abstractly to refer to that portion of the I.E. which "organizes" past O.E. behaviors and thereby uses new information in generating responses. In this sense it is useful to distinguish between a long term image (LTI) and a short term image (STI). The LTI includes representations of relatively invariant properties of the O.E. Within many bureaucracies formal standard operating procedures act as an LTI. More ambient or current information is stored in the STI. The contents of the STI are used in conjunction with the LTI to determine control procedure within the I.E.

This distinction between the STI and LTI together with the explicit concerns for modeling the way in which information is processed within bureaucracies mentioned above lead very naturally to a particular way of modeling control structures - that of production systems. A production system ". . . . consists of a set of productions, each production consisting of a condition and an action (Newell, 1973b, p. 463)."

Production systems thereby explicitly incorporate theoretical statements about operation and force the modeler to be explicit about detailed control structure. Of equal importance is the fact that the mathematical structure of the allowable objects is not very constrained. Production systems therefore provide a particularly desirable method of creating detailed constructive specifications of models of government. Structure is explicitly embedded and behavior can be simulated.

Essentially the only technical constraint on the realized system that is imposed by the production system method is that the time sets be discrete. That is, T must be isomorphic to the non-negative integers. Such time sets model discrete time in the ordinary clock time notion of discrete time and event time as well. In event time, only the ordering of the occurrence of events is recorded and not the clock time of the occurrence of the event.

With any discrete time set some simplification in the abstract model of the controller is possible. Inputs and outputs in this case are sequences of symbols from the alphabets, and a next state transition can be defined. That is, given a state decomposition

$$IE = \Phi o \Gamma$$

$$\Gamma \subset Y \times Z = A^T \times E^T$$

$$\Phi \subset Z \times U = E^T \times B^T$$

with T a discrete time set. It follows from

$$tr\Gamma = \{(((y_t)^{t'}, z(t)), z(t+t') | (y, z) \varepsilon \Gamma \wedge t, t' \varepsilon T\}$$

that a one step transition can be obtained by setting $t' = 1$. That is

$$1tr\Gamma = \{(((y_t)^1, z(t)), z(t+1) | (y, z) \varepsilon \Gamma \wedge t \varepsilon T\}$$

Since T is discrete

$$(y_t)^1 = y(t)$$

Therefore,

$$1tr\Gamma = \{((y(t), z(t)), z(t+1) | (y, z) \varepsilon \Gamma \wedge t \varepsilon T\}$$

Production systems provide a very general method for constructing this one step transition function.

Notice that by using a one step transition function and by assuming the same time set for inputs and outputs, we implicitly assume that the system responds to each input. This response can be no response, the null element in B, but a response in the form of some element in B must be produced. This causes no difficulty as long as the controller has sufficient time to make the state transition and produce an output before the next input from the environment is received.

This assumption is not a limitation of the production system method and can be eliminated through use of different time sets for the inputs, outputs, and states, but this introduces additional complexity that is not needed for this discussion. It is interesting to note in passing that the time scale problem is a common one in real time computer control systems (e.g., computer control of physical processes) but is generally not a critical issue in typical general purpose information processing applications.

As mentioned above, the role of production systems in modeling governments is in constructing mechanisms to realize the one step state transition function. All information processing requirements and operations must be explicitly defined and implemented. Specifically, productions are rules stated in the form of a condition and an action: C→A. In our terms, the "condition" refers to the contents of the STI and the actions may involve policy changes (u̲) intended to lead to goal satisfaction or, more frequently to changes (transformations) on the STI. These changes involve modification (including deletions) of content of STI as well as addition of new content (which may appear externally as a switch in control). A more complete description of the rules governing production systems is provided by Klahr (1973):

i. The productions are considered in sequence, starting with the first.

ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in (STI). If all of the elements in a condition can be matched with elements (in any order) in (STI), then the condition is satisfied.

iii. If a condition is not satisfied, the next production rule in the ordered list of production rules is considered.

iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).

v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.

vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.

vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost.

(p. 528-529).

An Example of a Production System

In order to illustrate the way production systems operate it will be useful first to discuss the basic operation of a portion of a preliminary production system model of the Saudi Ministry of Agriculture. Following this general discussion the actual production system will be treated in detail. As discussed above, a number of organizing principles have been employed as constraints on the construction of governmental control structures. Not all of those principles are directly reflected in the portion of the decision module which roughly corresponds to the Saudi Arabian Ministry of Agriculture presented here. In particular, the principles of hierarchical organization, redundancy of potential control, and multi-goal seeking are not represented because the simulation module employed here is only a portion of the total structure. In addition, since the decision module is a developmental version, the decision making properties of the module are at a relatively primitive state. In spite of these shortcomings, the module, as presented

above, does serve as a useful illustration of the basic techniques and its potential.

In essence, the decision module can be conceptualized as attempting to improve domestic agricultural performance as indexed by a function with two arguments (yield = f(fertilizer constraint on yield, mechanization constraint on yield). Within the agriculture module, the yield at any given point in time is a function of the level of fertilizer application and mechanization usage. The fertilizer constraint on yield can be expressed as follows: given the current level of fertilization, what is the maximum possible yield? The mechanization constraint has a similar expression since the actual yield will be constrained by the smallest constraint. If yield is to be increased, the lesser of the two constraints must be increased. The policy variables open the government in this simple example are the amount budgeted for governmental fertilizer purchase and the amount budgeted for governmental provision of tractors.

If the Saudi government budget is increasing, the motivation for the resultant governmental output is as follows: Assume there is more money to spend, the operant constraint is (say) fertilizer and mechanization. Mechanization could be decreased since some money spent on mechanization is wasted, but since it is not known exactly how the mechanization constraint behaves with respect to budget levels, and since money is "cheap" and decreased yields are "costly," it is more prudent to take the chance of "wasting" some money by spending more on fertilizer to improve the chance of increasing yield.

From a more operational perspective, it is required that governments make observations on the environment and base outputs upon those "perceptions" of the current state of the outer environment. As a result, inputs into the decision module are symbol strings describing the current mechanization and fertilizer cor[illegible]aints on yield as being very high, high, moderate, low, or very low. Judgments between high and very high represent finer distinctions than does a judgment between high and moderate. This scale and the use of a[illegible]rdinal description of the outer environ-

ment is based on two assumptions: The first is that the Saudi government does not have the information processing capacity to make (nor the measurement sophistication to use) finer distinctions. The second is that the Saudi's are capable of making relatively finer distinctions at the extremes of the scale. This claim about the capability of the Saudi's to process information is supported by Al-Awaji's (1971:147) description of the planning system as "institutionally fragmented and substantially ineffective," the lack of qualified manpower to staff the Saudi bureaucracy (Al-Awaji, 1971:218) for example, as of today, there still has not been a thorough census of the Saudi population.

Based upon the absolute judgments of the constraints, the decision module makes a comparison between the two constraints, resulting in relative statements such as: "The fertilization constraint is much greater than the mechanization constraint." This comparison reflects the fact that judgments are more fine grained at the extremum of the scale. One constraint is higher than another if a "boundary," i.e., the cutoff point between high and medium is crossed. For example, a very high constraint is judged greater than a high constraint, and a high constraint is judged greater than a medium constraint. If two "boundaries" are crossed, the comparison of that is very high. Thus, a very high constraint is very much greater than a medium constraint, and a medium constraint is very much higher than a very low constraint. If more than two boundaries are crossed, the comparison is 'much greater than.'

These two rankings of the constraints serve as the basic input to the choice portion of the production system. The structure of the decision module breaks the process of generating outputs into two portions. First the budget to be manipulated is determined, e.g., budget for fertilizer purchase, and/or budget for tractor purchase. Secondly, the amount of change in the budget's selected (increase a little, increase, increase a lot) is determined. The decision

module uses the first relative judgment (greater than) to determine which budget to manipulate. If one constraint is less than the other, the lowest constraint is chosen. If both constraints are "about the same," both budgets are increased. If the budget to be increased has a high or very high constraint, the budget is increased "a little." If the constraint is medium, the budget (or budgets) is simply "increased." If the level of the constraint is low or very low, the budget is increased "a lot."

An input-output table which shows the decision module response to fertilizer and mechanization budget constraint inputs is given in Table 1. It is clear from this table that this particular decision module is a static system. Only the current input information is needed to define the response that will obtain. This table corresponds to the general state decomposed model of the inner environment discussed previously. Based on the previous discussion of the decision module operation, it should be clear that the production system which is used to realize the system has a more complex internal structure than is apparent from the input-output or control description of the module. That is, the production system if functionally equivalent to the system defined by Table 1 but not structurally equivalent.

In the current implementation of the decision module, increase a little means to increase the budget by 20 percent, increase means increase the budget by 50 percent, and increase a lot means to increase the budget by 150 percent. Since the actual budget changes will in the final analysis be determined by the Council of Ministers, the current procedure represents only a temporary method for allowing a portion of the decision module to operate for testing purposes. The rates of increase should not be taken too seriously. In addition, the portion of the module discussed above assumes no budget decrease takes place.

In light of the above discussion of the rules upon which a production system operates, and the non-technical (from a programming point of view) discussion of the operation of the module, the portion of the agriculture module in Figure 2 should be fairly straightforward. The system in Figure 2 is that portion of the production system that takes the judgments of the size of the constraints and determines which budgets to increase and by how much they should be increased.

There is only one operator that was implemented, the ** operator. The ** operator takes the first element in the short term image (STI) and replaces it with the double stars. Thus, if the ** expression were: OLD (**) and the first element in the STI where $$$$$, then after the execution of the **, the front of STI would be: OLD($$$$$). This operator was necessary to insure that the system would not go into an endless loop. If a production were satisfied by the elements of STI, after the operation of the ** operator, the production would not be executed again, until the masked condition were reentered into STI.

As an example, consider the operation when the STI contains the symbols YMECH MEDIUM, YFERT GREATER THAN YMECH. The system starts with production 1. Since the conditions of production 1 are not in STI, the system checks production 2. This process continues until production 12 is executed. The elements in STI

match the conditions of the production, and the action portion of the production is executed. This results in 1) the elements in STI that matched the production conditions being placed in the front of STI; 2) the ** operator is applied to the first element in STI, YFERT GREATER THAN YMECH. The result is that OLD(YFERT GREATER THAN YMECH) is now the first element in STI; 3) the symbol string INCREASE BMECH A LOT is placed in the front of STI, moving all other symbol strings down one position; 4) control is passed to the first production. The system loops through the productions until none of the productions is satisfied. At that point control passes to the portion of the module responsible for taking these qualitative changes in the budgets and producing actual budget figures.

The agriculture decision module presented here serves only as a preliminary version upon which more sophisticated and reasonable modules can be based. Besides the obvious necessity of addressing the question of the validity of the simulations (see Thorson, Anderson, and Thorson, 1975 and Hermann, Phillips, and Thorson, 1975) there is need for future development in two main areas. The first is the development of the processing sophistication of the decision module. For example, it is necessary to model learning and adaptation within the bureaucracy. This development will require the use of more sophisticated inner environment models at the control system level. The second area is that of language processing. The quality of language processing becomes especially important when dealing with the international aspects of the outer environment. Diplomacy is in many respects a linguistic exercise. The capability for language processing entails that outputs from the simulations be sentences in a language. For the production systems to have this capability, several things are necessary. First the language and its associated grammar must be specified. Secondly, the routines must be written which will take

sentences describing either states of the environment or actions of other actors as input and produce perceptions of the current level of goal achievement to serve as inputs into the decision making portion of the system.

§ 8 CONCLUSION

In this paper we have attempted to develop and illustrate a perspective from which complete processing models of governmental control structures can be formulated. Specifically, it was argued that governments can be viewed as information processors and that attention must be paid to specifying the internal structure of the processor. This perspective was related to that of abstract control problems and connections between goals, control mechanisms and realizations were discussed. It was shown that while control mechanisms in general do not require explicit treatment of the internal structure of the processor, a functional equivalent of control mechanisms - production systems - does require such a specification. An example of a production system model of a portion of the Saudi Arabian Ministry of Agriculture was used to illustrate these points.

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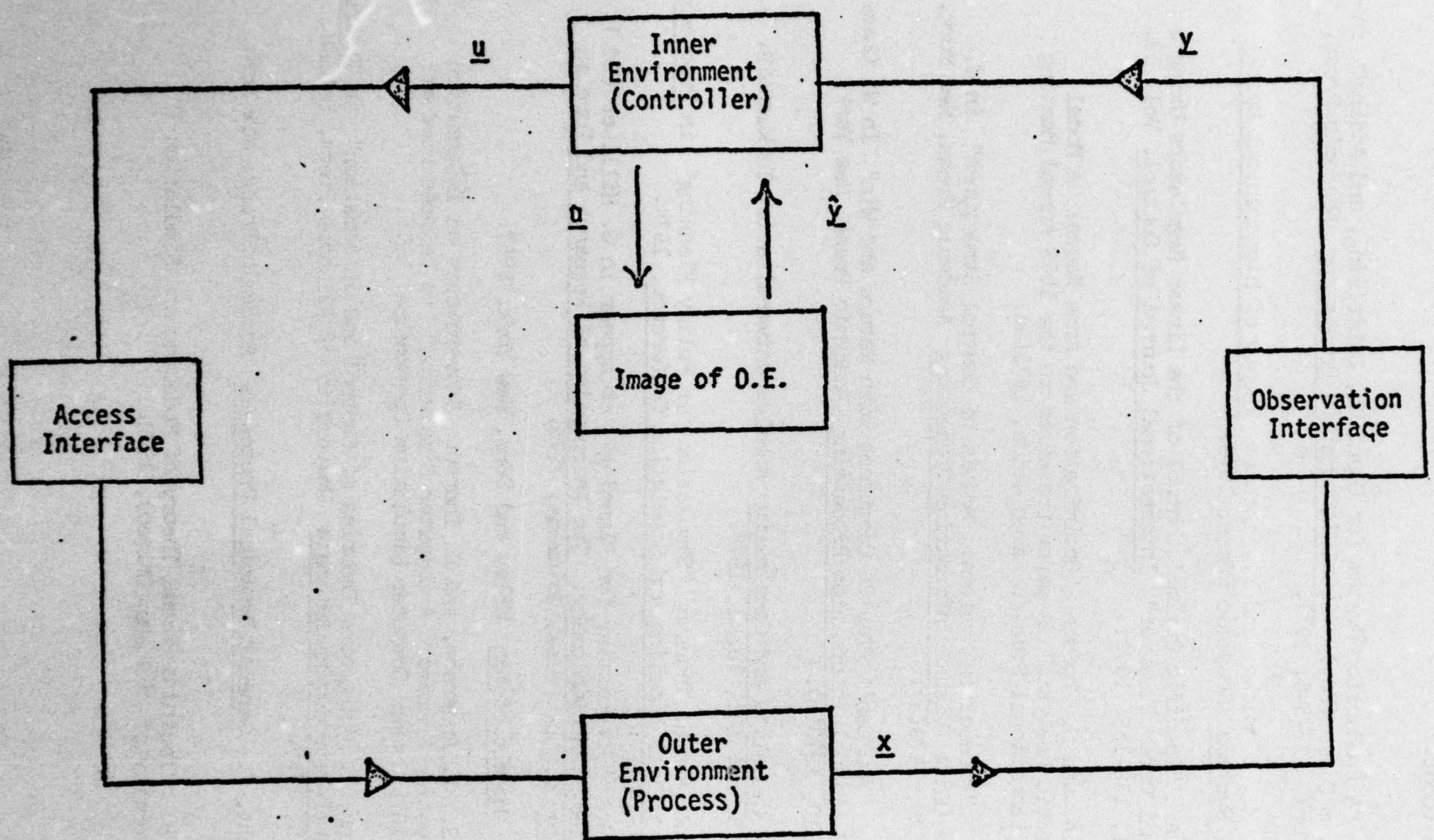

Figure 1 - Control System Structure

FIGURE 2 - A PRELIMINARY AGRICULTURE PRODUCTION SYSTEM

P1	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH LOW)
	Action	(OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)
P2	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH VERY LOW)
	Action	(OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)
P3	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH HIGH)
	Action	(OLD (**), INCREASE BMECH A LITTLE, INCREASE BFERT A LITTLE)
P4	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH VERY HIGH)
	Action	(OLD (**), INCREASE BMECH A LITTLE, INCREASE BFERT A LITTLE)
P5	Condition	(YMECH GREATER YFERT, YFERT VERY LOW)
	Action	(OLD (**), INCREASE BFERT A LOT)
P6	Condition	(YMECH GREATER YFERT, YFERT LOW)
	Action	(OLD (**), INCREASE BFERT A LOT)
P7	Condition	(YMECH GREATER YFERT, YMECH HI[illegible]
	Action	(OLD (**), INCREASE BFERT)
P8	Condition	(YFERT GREATER YMECH, YMECH LOW)
	Action	(OLD (**), INCREASE BMECH A LOT)
P9	Condition	(YFERT GREATER YMECH, YMECH VERY LOW)
	Action	(OLD (**), INCREASE BMECH A LOT)
P10	Condition	(YFERT GREATER YMECH, YFERT HIGH, YMECH MEDIUM)
	Action	(OLD (**), INCREASE BMECH)
P11	Condition	(YMECH GREATER YFERT, YMECH MEDIUM, YFERT VERY HIGH)
	Action	(OLD (**), INCREASE BMECH A LOT)
P12	Condition	(YFERT GREATER YMECH, YMECH MEDIUM)
	Action	(OLD (**), INCREASE BMECH A LOT)
P13	Condition	(YMECH ABOUT EQUAL TO YFERT, YMECH MEDIUM)
	Action	(OLD (**), INCREASE BMECH, INCREASE BFERT)

YMECH = Level of mechanization constraint
BMECH = Budget for mechanization
YFERT = Level of the fertilizer constraint
BFERT = Budget for fertilizer

Mech. Constraint \ Fertilizer Constraint	Very Low	Low	Medium	High	Very High
Very low	a lot a lot	-- a lot	-- a lot	-- a lot	-- a lot
Low	a lot --	a lot a lot	-- a lot	-- a lot	-- a lot
Medium	a lot --	a lot --	increase increase	-- increase	-- increase
High	a lot --	a lot --	increase --	a little a little	-- a little
Very High	a lot --	a lot --	increase --	a little --	a little a little

-- denotes no change.

The upper entry in each box is the fertilizer budget increase recommendation; the lower entry mechanization budget increase recommendation.

Table 1

Decision Module Input-Output Table

STRUCTURAL REQUIREMENTS

1. SPECIFICATION OF OUTER ENVIRONMENTS
   - DISTURBANCES
2. SPECIFICATION OF INTERNAL STRUCTURE OF CONTROL MECHANISM
   - DISTURBANCES
   - HIERARCHICAL ORGANIZATION
   - EVENT BASED
   - REDUNDANCY OF POTENTIAL CONTROL
3. MULTIPLICITY (AND PERHAPS INCONSISTENCY) OF CONTROL MECHANISM GOALS

Quasi-Experimental Effects of Military Assistance Upon International Conflict and Cooperation

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QUASI-EXPERIMENTAL EFFECTS OF MILITARY ASSISTANCE UPON INTERNATIONAL CONFLICT AND COOPERATION

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Effects of military assistance upon recipient nation international conflict relative to cooperation are investigated. Since traditional bivariate and multivariate statistical techniques are often conceptually inapplicable to this subject matter, a quasi-experimental design which relies upon autoregressive moving average models and exponential smoothing forecasting mechanisms is employed. Twenty-six annual observations, from 1946 through 1971, of fifteen Asian nations serve as the data base. Key findings are: (1) lump sums of military assistance tend to change the recipient nation's international conflict and cooperative behavior decidedly; (2) in a substantial majority of cases examined, the direction of that behavior change is toward increased conflict and decreased cooperation; and (3) a two year lag between military assistance and recipient nation international conflict relative to cooperation is statistically supported. Bureaucratic politics, habit, expectation, and prior deals are offered as possible reasons for these results. The paper's findings seem to refute the argument that giving military aid to a nation not involved in a war will help strengthen that nation and thereby avoid future conflict.

Is there a greater chance that a country will be involved in more international conflict relative to cooperation if that country receives one or a few large sums of military assistance[1] than if it does not? This is the primary question which I address in this paper. The answer is yes, the chance is greater.

I have divided this paper into five sections: (1) the reasons which led me to use quasi-experimental design; (2) a discussion of the various types of quasi-experimental design; (3) a description of my data set and variable operationalizations; (4) an elaboration of the path which I followed to answer my primary question, as well as a more detailed answer to that question; and (5) conclusions.

Why Use Quasi-Experimental Design?

Most statistical techniques used in international politics involve examining the patterns of two or more variables. They make the assumption that a dependent variable, domestic conflict for instance, changes in a manner related closely to the <u>variation</u> in one or more independent variables, such as military assistance. This seems to be a reasonable assumption in cases where the sequence resembles the following pattern: Inputs are made to a system; those inputs are eventually converted to outputs; and the outputs are sensitive to fluctuations in the inputs. For many countries, converting economic assistance to economic capacity is an example of this type of situation. Incremental changes in grants or loans can be expected to change the economic capacity of the recipient in a specifiable manner.

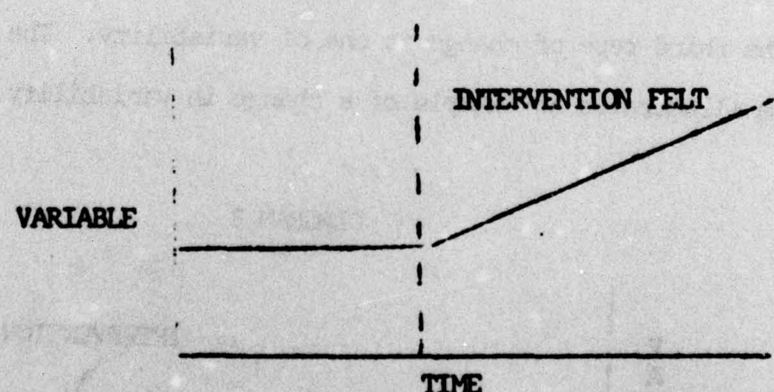
However, not all aid giving patterns are annual, and even when they are, the pattern may be one of fiscal rather than calendar years. I, therefore, hold that there is no reason to expect that variations in data on independent variables which is collected in annual segments will be reflected in similarly partitioned dependent variables. Influences on the effects of foreign assistance such as bureaucratic politics, psychological factors, and prior deals point to additional problems with traditional bivariate and multivariate techniques such as regression analysis. For instance, in a case where a large sum of assistance is given by one nation to another, and comparatively little additional assistance is given for a few years, the actions of the recipient nation (especially as captured by a variable such as international cooperation) might be motivated by a feeling of expectation of future aid from the donor. Therefore, what might appear, when observing annual segments of aid, to be a substantial decrease in value for the independent variable would not be reflected in the dependent variable's pattern of change. Receiving one lump sum of aid might cause expectation of another similar gift to motivate a recipient nation for a period of years. As I will discuss later in this paper, the same dependent variable pattern could result from either bureaucratic politics or prior deals.

These expected dependent variable patterns led me to choose quasi-experimental design over multivariate statistical techniques. I shall test the hypothesis stated by an affirmative answer to my primary question with lump sums of military assistance as the quasi-experimental intervention.

Types of Quasi-Experimental Design

Conventional quasi-experimental techniques, as elaborated by Campbell (1969), Campbell and Stanley (1966), Caporaso and Pelowski (1971), and Caporaso and Roos (1973), can detect three types of intervention effects. By intervention effects, I mean a change in the pattern of the dependent variable over time. One pattern exists before the effect of the intervention is felt and another exists afterward. The latter two of the three effects detected by conventional quasi-experimental designs assume a stationary (i.e., constant mean for a given side of the intervention line) dependent variable pattern. The three patterns are slope change, stationary level change, and change in variability. The following is a graphic example of slope change.

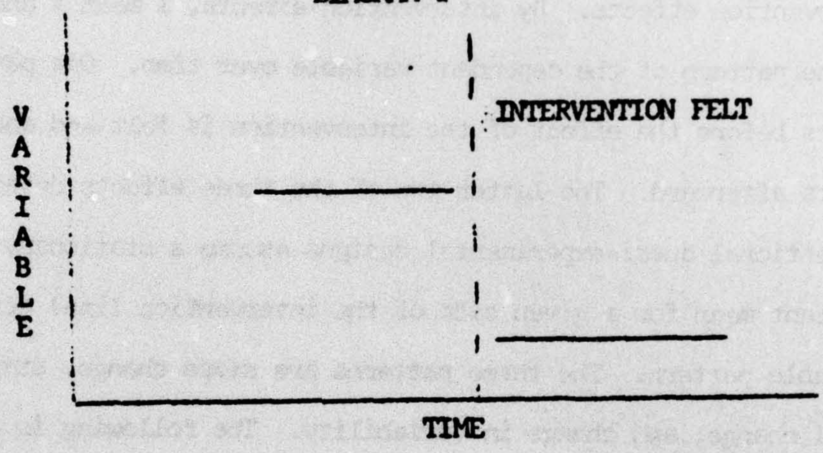
DIAGRAM 1



A hypothetical case where this type of slope change might occur is one where a boost (e.g., technological innovation leading to increased production) to a nation's economy increases the rate at which the GNP

grows. Stationary level change, a second type of intervention effect which can be detected by conventional quasi-experimental techniques, could look like this graphically:

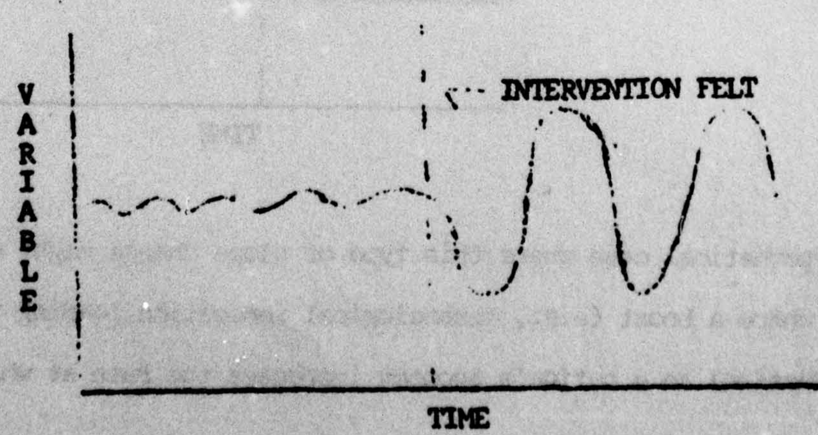
DIAGRAM 2



The 1970 floods in Bangladesh might well have produced such a change in the average individual food consumption in that country.

The third type of change is one of variability. The following diagram illustrates an example of a change in variability.

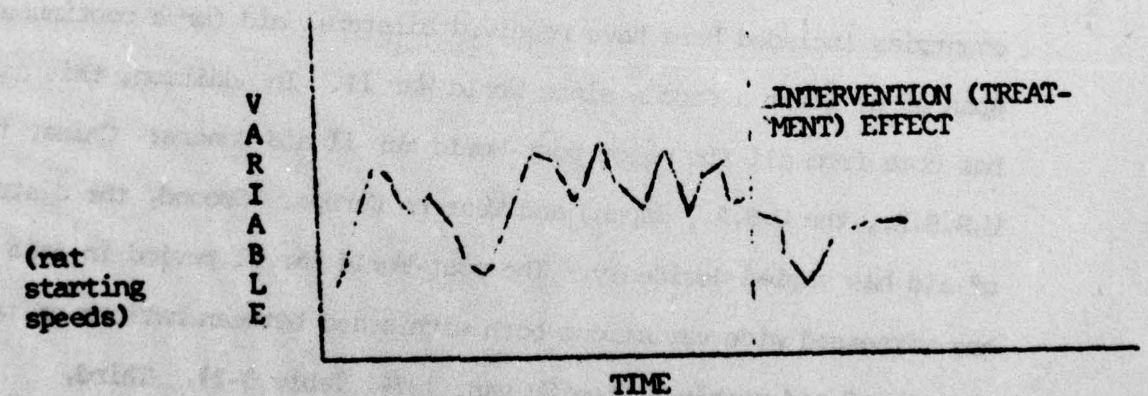
DIAGRAM 3



One example of this type of pattern change is a case where the economic stability of a nation is shaken, thereby increasing seasonal fluctuation of GNP, while the average GNP remains about the same.

The three conventional quasi-experimental tests which I have described thus far do not always reflect changes which have occurred. I shall, therefore, look at a fourth. It is a method introduced by Box and Tiao (1965) and carried further by Maguire and Glass (1967). The method evaluates the change in level between successive points in time in a non-stationary (i.e., a constant mean cannot be assumed) time series. Any situation resembling the one illustrated to Diagram 4 might well draw conclusions of either "no intervention effect" or "no determination of absence or presence of treatment effect can be made" if only

DIAGRAM 4[2]



the three tests of quasi-experimental influence which have been discussed thus far were applied. However, by applying either an autoregressive moving average (ARMA) model similar to the integrated moving average model employed by Box and Tiao, or an exponential smoothing forecasting

model, changes due to intervention which are at least in part obscurred on graphs by slight drifts, cycles or trends can be detected. In addition a comparison of actual post-intervention points with forecasts of those points based on a pre-intervention model, will detect any of the three quasi-experimental effects discussed previously. I will make such a comparison, and explain it in more detail, later in this paper.

Data Set Description and Operationalizations

The data set used in this paper consists of information on fifteen Asian countries.[3] Each of the two variables, military assistance and international conflict relative to cooperation (henceforth ICC) is observed annually for the twenty-six years from 1946 through 1971.

I chose to deal with these Asian countries for three reasons. First, the region contains many military assistance recipients. Each of the countries included here have received bilateral aid for a continuous span of at least a decade since World War II. In addition, this assistance has come from all the major post-World War II aid donors: China, the U.S.S.R., the U.S.A., Japan, and Western Europe. Second, the distribution of aid has varied decidedly. The post-World War II period in Asia has witnessed wide variations both within and between nations on the amounts of aid received (See Sylvan, 1974, Table 3-2). Third, relatively reliable data was more readily available for Asia than for other regions which may have had similar characteristics with respect to the first two reasons.

One of the two variables considered in this paper is military assistance. It is operationalized here as the amount of military aid

which a nation receives in a year divided by that nation's military expenditures. The demoninator is included in order to capture the aid's impact. My argument is that two million dollars of military hardware will mean less to a country with an extremely large military budget than to a nation with a small military budget. My primary sources for the military assistance variable were Bendix (1971) and the S.I.P.R.I. yearbook (1972).

International conflict relative to cooperation (ICC) has two equally weighted components. The international cooperation index consists of information on diplomatic visits bilateral and defense treaties, and shared U.N. voting. Values for each of these three variables are recorded for each country for each year. The highest such value for each variable is then given a score of 1000, while the lowest is set equal to zero. This creates an interval scale from which scores are assigned to all other observations. The three scores for each country-year are then added to arrive at a total for the international cooperation component. An international conflict component is then created in an identical manner, with the three contributing variables being territorial disputes, minority disputes and intensity of violent conflict. The total international conflict score is then subtracted from the international cooperation score to arrive at an ICC score for each country-year. Bendix (1971) served as the data source.

Description of Quasi-Experimental Design
Steps, and Answer to Primary Question

I followed six steps in answering my primary question through quasi-experimental design. The six were (1) choosing a control and an experimental group; (2) specifying a lag time; (3) forecasting post-intervention effect ICC values for each year in each country; (4) the "absolute value test; and (5) the directional test. The last two steps include interpretation of results. I shall now describe how I went about performing each of the five procedures, and report the results, thereby answering my primary question.

Choosing an experimental and a control group was the first step in my design. I argue that military assistance should only be treated as an intervention in cases where a country has received a lump sum of it. Therefore, only if a country had either (1) military assistance value which exceeded one (i.e., in a given year, military aid to a country was larger than the country's national military expenditure) or (2) an increase of over twenty times in military assistance values from one year to the next, did I include it in the experimental group. These two alternative criteria, then, become my operationalization of lump sum.[4] Based on these criteria, then, my experimental group consisted of Afghanistan, India, Indonesia, Laos, South Korea, Taiwan, and Thailand. The remaining eight nations constitute the control group. One challenge to any quasi-experimental design (see Campbell and Stanley (1963), p. 70) is that the experimental and control groups reflect something other than the division which they were designed to reflect. I have compared my two groups on a number of attributes and found none which clearly divide them into the two groupings examined here.

Dealing with the issue of time lags was the second task in my design. For this step I had to decide when I thought the lump sum of military assistance would take effect on the recipient's ICC behavior. In Sylvan (1974) I argue that a number of variables such as economic capacity, aid dispensing mechanisms and national integration intervene in converting assistance to ICC behavior. There, I conclude that a four year lag is appropriate. The body of this paper presents tests with that four year lag. The Appendix, however, tests zero, one, two, three, and four year lags, and finds slightly stronger results with a two year lag.

In cases where my lump sum criteria are met more than once for a country,[5] I treat the first lump sum observation as the intervention. The impression is made with the first gift. I argue, for example, that once a nation actually receives one lump sum of military assistance, its altered behavior pattern is set.

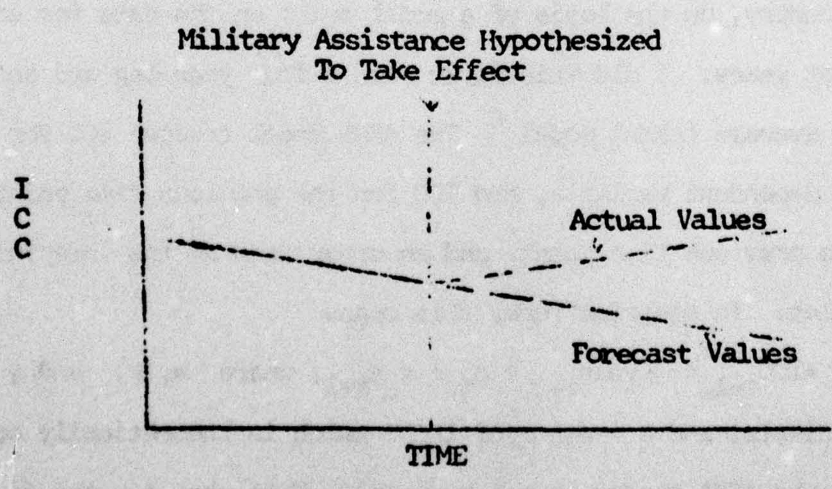
Step three was to forecast ICC values for all post-test years for each country, on the basis of a model built on the data for each country's pre-test years. I did this first with a four year lag and an autoregressive moving average (ARMA) model.[6] The ARMA model treated ICC for a given year as the dependent variable, and ICC for the previous time point, year for the previous time point, and an error term as the independent variables. In equation form, this means

$ICC_t = \alpha ICC_{t-1} + \beta\, year_{t-1} + e_t + \gamma\, e_{t-1}$, where α, β, and γ are coefficients, and e = error of ICC (which is theoretically accounted for by the ARMA random normal process). Note that for the first post-test year, ICC_{t-1} is an actual value, but it is a forecast value from then on. This is consistent with using only pre-test values to determine the effect of the intervention.

For the nations in the control group, I chose the midpoint of the available ICC time series as the intervention effect point. I did so because that point best approximated the intervention effect point for experimental group countries. The method by which I forecast ICC values for the control group countries' post-test period was identical to the procedure for the experimental group.

Step four in my quasi-experimental design was performing the "absolute value test." This is the first comparison between forecast and actual post-intervention effect ICC values. My general hypothesis is that experimental group forecasts should be less accurate than post-intervention effect forecasts for the control group. That hypothesis follows from the assumption that military assistance has an impact upon ICC behavior. Diagram 5 illustrates my point:

DIAGRAM 5



For experimental group countries the 'aid effect line' has a meaning, and one, therefore, would expect the difference between actual and forecast

ICC values to be greater than for control group countries, where the line is artificial. In the absolute value test, the percentage error[7] of the forecast value is computed in each post-test year by the following formula:

$$\text{percentage error} = \frac{|\text{actual} - \text{forecast}|}{1/2\ (\text{actual} + \text{forecast})}$$

After calculating the absolute value of the percentage error of the ARMA forecast of ICC for each year for each country, I averaged those absolute values for each country. Those figures are reported in Table 1. In order for those figures to relate to the primary question of this chapter, calculations of group means for the experimental and for the control groups are necessary. Such group means for all fifteen countries can also be found in Table 1.

TABLE 1

ABSOLUTE VALUE TEST FOR A QUASI-EXPERIMENTAL EFFECT OF MILITARY ASSISTANCE ON ICC

Experimental Group
(higher error percentages expected)

Country	Average of Absolute Value of Error Percentages of ARMA Forecasts of ICC
Afghanistan	31.804
India	43.341
Indonesia	75.261
Laos	58.422
South Korea	66.452
Taiwan	104.151
Thailand	12.250
GROUP MEAN	55.954
GROUP SUM	391.681

Control Group
(lower error percentages expected)

Burma	28.038
Cambodia	39.678
Ceylon (Sri Lanka)	53.552
Japan	17.831
Malaysia	16.518
Pakistan	17.577
Philippines	11.707
South Vietnam	59.024
GROUP MEAN	30.491

The logical next question is how significant the results reported in Table 1 are. My initial inclination was to apply a t-test of the difference of means. However, I have no reason to assume that the population of my statistical universe is normally distributed. Non-parametric statistics such as Mann-Whitney U would be another option, but I reject their requirement that I ignore information by considering my data to be ordinal rath er than interval in nature. One reasonable alternative is a simple comparison of group means to see if they differ in the expected direction. Table 1 shows us that the experimental group mean (55.954) is, as predicted, higher than the control group mean (30.491). The appendix shows us that all other lags also exhibit results in this direction. As hypothesized, the experimental group post-test forecasts was always less accurate than control group post-test forecasts. Military assistance appears to be having the expected effect on ICC behavior.

To further test these preliminary findings, I have adopted an approach which is entirely different than any discussed thus far.[8] Instead of treating the fifteen Asian countries as a random sample of the world, I leave it to each reader to decide how representative this group is of the Third World aid recipients to which I would like to generalize. The variety of aid donors and aid amounts in Asia during the 1946-1971 period lead me to see them as reasonably representative. However, the test reported here makes no assumption that the countries or data studied here are statistically representative of any larger group. Instead, it treats the fifteen nation groupings as its universe. It asks the question, "Given the actual distribution of the 15 country average national error percentages from which samples of size seven are drawn, exactly how likely is it that a seven nation sum of average error percentages would be equal to or greater than the sum of average

national error percentages for the seven nation experimental group?" No approximations or statistical assumptions are involved because the universe is known. The answer for the data in Table 1 to the question just posed can be found in Table 2.

TABLE 2

CUMULATIVE PROBABILITIES OF 7 COUNTRY GROUP SUMS GIVEN TABLE 1 ERROR PERCENTAGE VALUES

Seven Country Sum of Absolute Values of Average National Error Percentages	Probability of That Sum or More
211	.95
229	.90
241	.85
251	.80
259	.75
267	.70
275	.65
282	.60
289	.55
296	.50
303	.45
310	.40
317	.35
325	.30
333	.25
342	.20
352	.15
365	.10
382	.05

Table 2 tells us for instance, that seventy-five percent of the possible seven country sums of absolute values of national error percentages were either equal to or greater than 259. From Table 1 we see that the sum for the seven country experimental group was 391.681. Table 2 tells us that less than five percent of the seven country sums were 382 or

higher. Actually, there is only a .030 chance of achieving the experimental group sum or higher given the distribution of error percentages in Table 1. Except for the zero year lag, Appendix Table 1 shows us that for all lags tested, the results would be obtained 7.5 percent of the time or less.

This means that those countries which received a lump sum of military assistance exhibited a substantially greater departure of ICC from the amount forecast for the post-test period than did countries which did not receive such assistance. These test results are clearly consistent with an answer of yes to this paper's primary question.

A directional or raw value test served as the fifth and final step in my quasi-experimental design. This directional test directly questions a recommendation such as, "We should give military assistance to country x. After all, they are not now involved in a war (i.e., their present national military expenditures are not very high), so giving them military assistance will help strengthen them and thereby avoid future conflict." With this step, I tested to see whether the experimental group exhibited higher levels (with respect to forecasts from a pre-test model) of international conflict with respect to cooperation (as opposed to merely exhibiting the higher deviations from forecasts which the absolute value test showed) in the post-test period than did the control group. The initial steps in this directional test were identical to the initial procedures in the absolute value test. Both forecast ICC for each post-test year and compare those forecasts with actual post-test values. However, the directional test uses the raw value of the error percentages rather than the absolute values. This is reflected in the formula

$$\text{percentage error} = \frac{\text{actual forecast} - \text{forecast value}}{1/2(\text{actual} + \text{forecast value})}$$

TABLE 3

RAW VALUE OR DIRECTIONAL TEST FOR A QUASI-EXPERIMENTAL EFFECT OF MILITARY ASSISTANCE ON ICC

Experimental Group
(higher or more positive error percentages expected)

Country	Average of Raw Value of Error Percentages of ARMA Forecasts of ICC
Afghanistan	-25.475
India	5.692
Indonesia	- 9.424
Laos	23.417
South Korea	40.807
Taiwan	80.987
Thailand	11.035
GROUP MEAN	18.148
GROUP SUM	127.039

Control Group
(lower or more negative error percentages expected)

Country	Average of Raw Value of Error Percentages of ARMA Forecasts of ICC
Burma	11.074
Cambodia	-18.553
Ceylon (Sri Lanka)	-48.663
Japan	5.469
Malaysia	-16.202
Pakistan	-17.112
Philippines	- 7.733
South Vietnam	-56.071
GROUP MEAN	-18.474

As Table 3 reveals, the experimental group mean was 18.148, while the control group mean was -18.474. This seems to be a clear cut difference in the hypothesized direction. This paper's appendix shows us that the group means are very close for the zero and one year lags, while the other lags exhibit differences in group means which are more clear cut, and in the hypothesized direction. Among the appendix findings, the two year lag again produces the most striking result.

To substantiate the directional (or raw value) test differences of means findings, I again relied upon a probability test given exact distributional data. It showed that a value equal to or greater than the experimental group sum reported in Table 3 (127.039) would only occur with a .017 probability. In other words, this result is in a select group of only 1.7 percent of the strongest results attainable with the distribution of error percentages reported in Table 3. Appendix Table A-2 shows weak results for zero and one year lags on the directional test, with stronger results for the other lags, two years exhibiting the strongest.

Results such as the .017 probability just reported clearly move in the direction of a "yes" answer for this paper's primary question.

The policy recommendation mentioned at the beginning of this step seems resoundly refuted: the situation where military aid is given to a country which is not in a war (comparatively low national military expenditures) is exactly the situation which this test shows is likely to lead to higher levels of conflict than if the assistance were not given.

In an effort to explain why I have found that there is a greater chance that a country will be involved in more international conflict relative to cooperation if that country receives one or a few large sums of military assistance than if it does not, I shall return to the three alternative explanations advanced earlier. The three are bureaucratic politics, psychological factors, and prior deals.

One bureaucratic politics explanation of the results would be attributing them to a bureaucrat in a donor nation who sought an increase in his or her national leverage. Such a bureaucrat might have reacted quickly as a conflict broke out, and "juggled" the present and unreleased past figures on amounts of military assistance to make it appear as though (s)he foresaw the conflict and tried to avert is by giving military aid to the side which the bureaucrat now knows his or her government favors. Another bureaucratic politics explanation of the results is even more amoral. It is possible that a bureaucrat identified with the military sector in a donor nation sought to improve his position. He purposely manipulated military assistance to encourage war, because war demonstrates uniqueness, and in a zero sum budgeting game uniqueness is quite helpful in improving one's position. A third bureaucratic politics explanation might involve the bureaucratic politics of a recipient nation. A recipient nation bureaucrat might have helped hasten the onset of conflict in order to strengthen the military institutions of his country.

Habit and expectation are the two major psychological factors[9] which I feel might explain my results. Both factors can help interpret reactions of recipients to lump sums, as opposed to regular annual

sums of military assistance. In the case of habit, the recipient continues to reap many of the benefits of the aid (e.g., a type of military hardware which does not require a great deal of maintenance), and reacts as though the aid were continuing at a constant level. If this were the case, the results could be interpreted as if they were regression results: increased amounts of military hardware on hand produces increased conflict. In the case of expectation, a nation might become involved in more conflict because it expects its military assistance to increase.

A third possible explanation of the results would be a prior deal. In a case where it would be advantageous to a donor to see a war change the status quo, that donor could make a deal with an aid recipient that if the donor supplied an abundance of money, the recipient would cooperate with the donor by going to war with a third country.

CONCLUSIONS

Is there a greater chance that a country will be involved in more international conflict relative to cooperation if that country receives one or a few large sums of military assistance than if it does not? According to the statistical evidence presented in this paper, there is clearly a greater chance. I have advanced a number of plausible explanations for this finding, but I do not have the data to choose between them. A more thorough model of the process of converting military assistance to ICC is necessary for that. My only hint at the process is that the conversion appears to take around two years.

The clearest finding of this paper comes from the "absolute value test": lump sums of military assistance tend to change recipient nation international conflict and cooperative behavior decidedly. Directional tests have shown us that in a substantial majority of the cases the direction of that behavior change is toward increased conflict and decreased cooperation.

APPENDIX: TESTING DIFFERENT TIME LAGS

As noted in the body of this paper, my original research pointed toward a four year lag between the time military assistance is given and the time such assistance is reflected in ICC behavior. The tests presented thus far dealt only with that four year lag. In this Appendix, I present tests of 0, 1, 2, 3, and 4 year lags.[10] Because I changed academic institutions between the original and follow-up tests, I can no longer readily access an autoregressive moving average (ARMA) forecasting routine which is applicable to a 26 year time series. Therefore, the tests reported in this Appendix are based on a different, slightly less accurate, forecasting model. The forecasting routine uses exponential smoothing, and was developed by James A. Bartos and David G. Fish (1974), as adopted from Winters (1960). Like ARMA forecasting, the exponential smoothing routine adjusts for trend, but not as finely. However, I hold that as long as I use the same forecasting algorithm for each country included in a given comparison of country groupings, any inaccuracy or distortion will be constant, and thereby cancel out. In other words, I can compare experimental and control groups if both sets of error percentages are generated by the same forecasting routine. Comparisons of ARMA and exponential smoothing forecasts without adjustment for a constant factor would be invalid, however.

Table A-1 presents "absolute value" error percentages for 0, 1, 2, 3, and 4 year lags as obtained with the exponential smoothing forecasting routine.

TABLE A-1

"ABSOLUTE VALUE" ERROR PERCENTAGES

Experimental Group
(higher error percentages expected)

Country	0 Year Lag	1 Year Lag	2 Year Lag	3 Year Lag	4 Year La
Afghanistan	85	32	42	14	51
India	75	727	6568	591	276
Indonesia	114	1166	66	14	12
Laos	40	173	48	160	78
South Korea	46	49	208	85	61
Taiwan	252	144	94	113	109
Thailand	70	11	23	8	11
GROUP MEAN	97.4	328.9	1007	140.7	85.4
GROUP SUM	682	2302	7049	985	598

Control Group
(lower error percentages expected)

Country	0 Year Lag	1 Year Lag	2 Year Lag	3 Year Lag	4 Year La
Burma	324	216	75	15	32
Cambodia	38	43	43	44	46
Ceylon	36	31	36	27	52
Japan	88	25	24	45	26
Malaysia	62	43	40	20	39
Pakistan	9	18	11	17	16
Philippines	14	7	12	12	13
South Vietnam	59	149	67	48	36
GROUP MEAN	78.7	66.5	38.5	28.5	32.5
PROBABILITY OF EXPERIMENTAL GROUP SUM OR GREATER	.312	.075	.026	.029	.041

Note: All country entries are average national error percentages of post-intervention effect forecasts.

This table is constructed in a manner parallel to Table 1, and its results are discussed in the body of this paper. I shall merely re-emphasize here that "probability of experimental group sum or greater" refers to the same exact probability testing procedure elaborated upon in the text and illustrated for another example with Table 2. The reader will note that while four of the five probabilities are extremely strong, a two year lag produces the strongest.

Table A-2 presents results for the directional test. As discussed in the text, it parallels Table 3, and again finds two year lag results to be the strongest.

TABLE A-2

"RAW VALUE" OR "DIRECTIONAL" ERROR PERCENTAGES

Experimental Group
(higher error percentages expected)

Country	0 Year Lag	1 Year Lag	2 Year Lag	3 Year Lag	4 Year Lag
Afghanistan	85	31	42	8	51
India	43	727	6568	591	276
Indonesia	54	-632	66	14	11
Laos	-31	132	-28	-5	-14
South Korea	-26	13	128	83	9
Taiwan	252	-144	-[illegible]3	-113	-109
Thailand	-70	-10	23	-2	7
GROUP MEAN	43.9	16.7	958	82.3	33
GROUP SUM	307	117	6706	576	231

Control Group
(lower error percentages expected)

Country	0 Year Lag	1 Year Lag	2 Year Lag	3 Year Lag	4 Year Lag
Burma	324	216	75	4	22
Cambodia	26	29	27	23	2
Ceylon	-35	-26	16	-17	18
Japan	88	-19	13	39	16
Malaysia	-62	-43	-40	-[illegible]	21
Pakistan	-4	-17	6	14	-14
Philippines	9	3	-4	5	-3
South Vietnam	43	54	67	43	27
GROUP MEAN	485	24.6	20	12.8	13.4
PROBABILITY OF EXPERIMENTAL GROUP SUM OR GREATER	.473	.528	.215	.332	.367

Note: All country entries are average national error percentages of post-intervention effect forecasts.

NOTES

[1] As elaborated upon later in this paper, military assistance is operationalized by dividing aid by national military expenditures.

[2] Taken from Maguire and Glass (1967), p. 747.

[3] Afghanistan, Burma, Cambodia, Ceylon (now Sri Lanka), India, Indonesia, Japan, Laos, Malaysia, Pakistan, Philippines, South Korea, South Vietnam, Taiwan, and Thailand.

[4] There is a clear enough division between groups, though, so that almost any similar criteria would have resulted in the same experimental and control groups.

[5] No country meets them more than three times.

[6] For a more detailed description of autoregressive moving average models, see Box and Jenkins (1970), Werbos (1974), and Sylvan (1974).

[7] The error percentages reported in Tables 1 and 3 may be deflated because of the assumption that the error term and the independent variable are uncorrelated. While this bias cancels out in the probability test reported next, the reader should not interpret the percentage error terms literally. For an excellent discussion of bias present in assuming 0 correlation between error term and independent variable, especially in cases (such as this one) where the dependent variable at t-1 is treated as an independent variable, see Hibbs (1974).

[8] I thank Stuart Thorson for his suggestion to use this test.

[9] For a discussion of the related subject matter of cultural and other factors underlying American attitudes toward foreign aid, see Geiger and Hansen (1968).

[10] For an example of experimentation with different lags on a different subject matter, see Terhune (1970). I did not test lags beyond five years, because of the decrease in the number of points in the post-test period in a total 26 year time period.

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Goals and Goal-Directed Behavior in International Relations*

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The study of international relations, as are all the social sciences, is deeply concerned with purposive behavior, and goal-directed, or teleological systems. Indeed nothing in the field of international relations is more basic than the notion of goal-directed behavior for "political" activities are largely "purposive" activities. Whether under the rubric of interests, objectives, ends, or goals, scholars have, either implicitly or explicitly, always thought of and explained international politics and foreign policy in terms of preferred end-states. Yet, despite the fundamental conceptual role played by goals in the understanding of international politics, its treatment as a concept has been unsatisfactory. For a variety of reasons to be discussed later, it remains an elusive, primitive term defying adequate conceptualization.

THE FUNCTION OF GOALS IN INTERNATIONAL RELATIONS THEORIZING

Any science aspiring to theory must assume some sort of underlying regularity in the world. Without positing such regularity, descriptive laws of nature and scientific predictions become impossible. Researchers would be forever limited to particular statements on unique events. Generalizations, without some posited order in one's universe of discourse, would be, at best, blind leaps of faith.

In the physical sciences, the regularity assumption is provided by a "mechanical postulate" which presupposes an order in the physical world independent of spiritual or metaphysical forces. Physical entities are assumed to exhibit regularities in behavior about which scientific theories can be framed.

In the social sciences, the regularity assumption is often introduced by the notion of goal-directed behavior. As noted by Riker and Ordeshook:

> When one is generalizing about the physical world, the conventional postulate is the mechanistic one; that is, we rule out vitalism, divine intervention, luck, witchcraft, and so on. When one is generalizing about the social world, however, where, clearly, the actors are vital, one can hardly rule out vitalism. Hence the postulate for regularity changes to a notion of the pursuit of goals; that is, we assume actors in society seek to attain their purposes.[1]

Attributing goal-directed behavior to social entities allows us to make sense of observed regularities in social behavior. It provides a rationale for theorizing and predicting regularities with some degree of assurance. It provides a specification for the meaning of an action and how it might be distinguished from other forms of behavior.[2] Finally, attributing goal-directed behavior to a social entity often eases the knowledge requirements of the entity's internal structure necessary for prediction. For example, in an economic context, Herbert Simon notes:

> If we know of a business organization only that it is a profit-maximizing system, we can often predict how its behavior will change if we change its environment -- how it will alter its prices if a sales tax is levied on its products. We can make this prediction -- and economists do make it repeatedly -- without any detailed assumptions about the adaptive mechanism, the decision-making apparatus that constitutes the inner environment of the business firm.[3]

Two basic strategies exist for employing the goal-directedness assumption in social science theorizing. Riker and Ordeshook call them revealed preference and posited

preference.[4] In the revealed preference procedure, rules of behavior (e.g., transitivity, utility maximization) are posited and then applied to observed behavior to discover those goals consistent with the aforementioned posited rules and observed behaviors. Hence, under the revealed preference strategy, goals are inferred from (1) assumptions about behavior, and (2) behavior actually observed.

In international relations research, revealed preference strategy is illustrated by what Graham Allison calls the "rational actor" mode of analysis:

> If a nation performed a particular action, that nation must have had ends toward which the action constituted a maximizing means. The Rational Actor Model's explanatory power stems from this inference pattern. The puzzle is solved by finding the purposive pattern within which the occurrence can be located as a value-maximizing means.[5]

In a somewhat stylized example, if an analyst assumes Communist nations with strong armies seek to increase their spheres of influence, and then notices the People's Republic of China (PRC) maintains a very large army, he could conclude, under the rational actor approach, the PRC's goal is to apply external, strategic military pressure abroad. Unfortunately, this mode of analysis is far from foolproof since an imaginative analyst, given a set of observed behaviors and posited rules of behavior, can usually find some set of goals consistent with his observations and opening assumptions.

The second, posited preference strategy assumes a given goal for an actor and certain rules of behavior. The actor's behavior is then inferred. If these inferences are confirmed by observation, our confidence both in the initial posited goals for the actor and the posited rules of behavior is increased. But, if our inferred behavior

for the actor doesn't occur, then either our posited goals or posited rules of behavior, or both are faulty.

In general, the analytical choice between revealed preference and posited preference is dependent on the problem being addressed. Often, research requires shifting between the two methods. For example, we noted earlier how an analyst, operating from a revealed preference perspective, might conclude the People's Republic of China's goal (we are, of course, assuming here a unitary actor perspective) is the aggressive exertion of military pressure abroad. However, assume further observations reveal the PRC's foreign activities to be defensive and cautious, contrary to posited preference expectations. The analyst would then be forced to alter his posited PRC goal (i.e., aggressive military expansion) or his initial, posited rule of behavior (i.e., Communist nations with strong armies are expansionist) or both, and then restart his analysis. In the process of such modification -- formulating goals and rules of behavior, comparing inferred behavior with observed behavior, reformulating goals and rules, etc. -- the analyst shifts from posited preference to revealed preference and back again. Both modes are necessary, one complementing the other.

To be of analytical value, the cyclic use of posited and revealed preference strategies requires careful conceptualization and explicit framing of theoretical assumptions. Such conceptual standards, unfortunately, have not often characterized the past treatment of goals and goal-directed behavior in the study of international relations. We now examine the conceptual state of goals in international relations research.

PAST TREATMENT OF GOALS IN INTERNATIONAL RELATIONS

Among traditional international relations scholars, goals have often been stipulated in an a priori manner. Hans Morgenthau, for example, saw power as the constant aim dominating international politics. Unfortunately, Morgenthau's

historical style of analysis and his strong prescriptive bent clouded his theoretical intent. While initially defining power as psychological control between individuals, Morgenthau applied the term to nations without addressing the resulting levels of analysis problem. Further, depending on the context and Morgenthau's purpose, power could be a relationship, a goal of policy, a stimulus for policy, and a means for realizing policy ends. Given this unusual flexibility in the use of the term, almost every conceivable behavior was interpreted as a pursuit for power.

Operating from a similar, traditional perspective, Haas and Whiting[6] identified self-preservation, self-extension, and self-abnegation (i.e., policies of retrenchment or withdrawal) as basic goals in international politics. To take a final example of traditional goal positing, Puchala's[7] list of fundamental goals included self-preservation, security, prosperity, prestige, and peace. Generally, these enumerative, a priori approaches to the goals of international politics were unsatisfying for similar reasons. First, they were defined too abstractly and imprecisely to be of much analytical use. What does it mean, for example, for a nation to strive for self-preservation or prosperity? How can one decide whether particular policies are in accord with such nebulous goals as peace or security? For example, was American intervention in Vietnam a contribution toward U.S. security or self-preservation? Second, a priori stipulation of national goals implied a homogeneous, unitary actor interpretation of nations which wasn't capable of treating internal policy dissension or bureaucratic political processes. Differences over concrete questions of policy implementation were left unexamined. Further, goal priorities and goal conflicts were difficult to handle at this rarefied level of abstraction. Third, the dynamic quality of goal formulation and transformation was ignored. Stipulation of a priori goals implied a permanence of interest independent of internal politics, external international change, and time which was highly questionable. For example, even such a primary "goal" as national self-preservation

might, in extraordinary circumstances, be suspended as in 1938, when Austrians voted overwhelmingly for Anschluss and political domination by Nazi Germany.

Another approach toward goals adopted by traditional scholars involved the identifying of underlying goal dimensions and the constructing of a classification based on these dimensions. For example, time has served as an underlying dimension for goal classification (Organski's long-range vs. immediate goals). Other goal dimensions proposed: core values vs. instrumental ones (Holsti, 1967), vital vs. secondary goals (Hartmann, 1957), general vs. specific goals (Organski, 1968), competitive vs. absolute (Organski), unified vs. divergent (Organski), national vs. humanitarian (Organski). Unfortunately, these approaches also suffered from the same conceptual problems noted above. While perhaps descriptively appealing, these goal images were too abstract, too nebulous, to capture the dynamic, diverse, and contingent quality of goals and goal-directed behavior.

The weaknesses connected with this sort of traditional, macro-level conceptual treatment became increasingly evident as scholars adopted more formal research strategies. Operationalization and the demands of mathematical tractibility often required more theoretical structure for goals than was available. This problem of structure, what Mesarovic and Thorson refer to as constructive specification,[8] was met in a number of ways. One strategy sidestepped the goal problem by adopting a macro-level perspective depending on aggregate indicators for description and international trend analysis. Work in international integration (Deutsch et al., 1957), international organizations,[9] and field theory (Rummel, 1963) serve as examples. Such monitoring and mapping activities allowed the use of statistical or linear algebraic analyses while avoiding the explicit treatment of goals.

Another strategy dealt with goals by positing them at a particular level of analysis. Game theoretic treatments, for example, viewed goals in terms of relative payoffs between players in highly structured conceptual settings. The players were

seen as unitary actors at a fixed level of analysis (such as the nation-state, the bureaucracy, or the individual). By abstracting away the complexity of goals and goal contexts, the analytical power of game theory could be utilized to the fullest measure. Similar conceptual simplifications concerning goals, for the sake of mathematical tractibility, were made in arms race process modelling à la Lewis Richardson (Richardson, 1960). Here, the differential equations which specified national arms race behavior were the posited goals.

Similar goal positing was also adopted when international systems theorizing, characterized by equilibrium interpretations of system behavior, came into vogue. McGowan,[10] for example, collapsed the myriad goals pursued by groups within a nation-state using a series of difference equations. National goals were interpreted as the need to "dampen" the paths produced by these difference equations over time -- a rather unorthodox goal conception, required by the mathematical techniques McGowan wished to employ.

Unfortunately, the international systems approach, like its predecessors, failed in general to deal meaningfully with purposive behavior. The approach often lapsed into an anthropomorphic mode of explanation whereby international systems assumed the character of holistic entities imbued with imminent, purposive rules of behavior. For example, Morton Kaplan, in his systems approach to international politics (Kaplan, 1957) posited "essential rules" for system members deemed necessary for a system's existence. Yet, the nature of these rules was unclear. They might be interpreted as operating "automatically," akin to Adam Smith's invisible hand; they might be "semi-automatic," requiring the conscious rule promoting efforts of "select" nations; or they might be "manual," requiring the full and conscious participation of all nations in the system.[11] In short, these rules of behavior seemed somehow prior to concrete activity. This same "a priori" treatment of purpose as a need-fulfilling function of a reified system of components also

characterized McGowan's theoretical treatment of national foreign policy mentioned earlier.

The general systems approach of Talcott Parsons[12] was another example of a macro-level systems perspective with an "a priori," need-fulfilling quality. Operating at a high level of abstraction, Parsons defined four essential functions every social system must satisfy to assure its survival -- pattern maintenance (i.e., the preservation of essential system traits), adaptation, goal attainment, and integration (i.e., the coordination of system components). Like Kaplan's work, the Parsonian systems perspective suggested innate system purposes lurking behind the scene.

Unfortunately, treating need-fulfilling functions of a system (what sociologists call the functional requisites for survival) as system goals was misleading. While a strong empirical connection between need-fulfilling, survival functions and system goals wouldn't be surprising (since those systems available for observation are those most likely to have survived for some time), survival functions and goals needn't be identical. For example, explaining the increase of white cells in the bloodstream during infection in terms of its survival function and natural selection would be biologically sound; explaining it as a collective goal pursued by the body would be bizarre. Similarly, in a political context, American actions in Vietnam might be explained in terms of Presidential goals; but, less plausibly so in terms of national functional requisites, again suggesting survival functions and goals needn't be synonymous. In general, if need-fulfilling functions resemble goals, the resemblance is empirical, not definitional. Nothing requires that goals have survival value.

Yet, despite the shortcomings of the systems school, it did reemphasize, though not always explicitly or consistently, an important aspect of purposive behavior which had been obscurred by the earlier "point-blank" positing of goals. That is, the systems

perspective was usually not of the form "the goal of the nation-state is power, prestige, wealth, and the like." Universal drives were not ascribed to nations. Rather, system treatments of goals made allusions, however obliquely, to the existence of a process or environment. Purposive behavior was imbedded within a context of system entities or interactions. This view, that goals are linked to some environmental context, that is, are context dependent, is important and will receive more treatment later.

When we move down to the organizational or bureaucratic level of analysis we find treatments of goals which seek to move away from goal positing and the attendant danger of reifying organizations while, at the same time, avoiding the mistake of assuming organizational goals are simply the accumulated goals of all its individual members. One approach is Stuart Thorson's use of production systems, essentially a simulation utilizing a list of "productions" (i.e., instructions) processed sequentially, to represent the control structure of a government.[13] The productions or instructions which produce government behavior are the government's goals; that is, the production system structure is the government's goal structure.[14] The production system approach is especially attractive for two important reasons. First, unlike many mathematical modeling approaches, it doesn't require a high degree of constructive specification (i.e., the formal, mathematical properties introduced in one's axiomatic structure for deductive convenience). The productions can be couched in very general, qualitative terms -- an important working and conceptual advantage since international relations has no guiding theories of any high precision. Second, since few restrictions govern the list of productions, the production system scheme has a large degree of flexibility which might be used to model multiple goals, goal conflicts, and redundancy of potential control (whereby subgoals can shift depending on internal and external circumstances). Hence, this flexibility potentially allows one to move well beyond macro-level goal positing.

Another imaginative approach, suggested by Herbert Simon,[15] involves conceptualizing organizational goals in terms of constraints or requirements which must be satisfied before an organization embarks on a course of action. In particular, organizational goals, he suggests, might be characterized by the constraint sets and goal searching criteria of the upper level decision-makers in the organization. While analyzing such constraint sets would not, by themselves, fully define organizational behavior, Simon argues they capture most of the "goal-like" properties associated with decision-making. Unfortunately, Simon's approach towards goals is not completely satisfying because: (1) the notion of constraints isn't sharply specified; (2) the upper level decision-makers, whose constraint sets are used to define goals, aren't identified clearly; and (3) all Simon's organizational examples are drawn from highly structured settings such as factory assembly lines, feed manufacturing, and investing. Nonetheless, Simon's view of goal as constraint set is intriguing because it relates goals to decision-making structure, it can treat multiple goals, and it moves beyond simple goal positing.

James Thompson suggests a different way of avoiding the reification problems connected with group goals. He defines organizational goals as goals specified for the organization by a dominant coalition. Thus, the pitfall of ascribing "intent" to an abstract organization is avoided. From Thompson's perspective, "organizational goals are established by individuals -- but interdependent individuals who collectively have sufficient control of organizational resources to commit them in certain directions and to withhold them from others."[16] Unfortunately, Thompson's conception of goals is not without difficulties. The twin problems of defining coalition goals and identifying dominant coalitions are left untreated. Like Simon's constraint approach towards goals, the dominant coalition approach remains an embryonic, suggestive attempt. However, Thompson does move beyond simple goal positing towards some notion of organizational goals which is linked to organizational decision-making structure.

Another approach towards goals, related to Thompson's dominant coalition attack, springs from an emerging movement to harness events data for foreign policy decision-making research. One events data perspective[17] defines nation goals as all goals expressed by "authoritative decision-makers" (i.e., governmental representatives with formal responsibility for policy-making) and reported publicly. Goals are never inferred from behavior.

Potentially at least, this particular events data perspective can handle multiple goals, contradictory goals, and differing goal priorities. Further, unlike Thompson's approach, the problem of identifying coalitions doesn't arise. However, the question of specifying "authoritative decision-makers" remains. Moreover, the professed goal definition is not linked explicitly to organizational processes or structure. Unlike the Thorson, Simon, or Thompson perspectives, its role is more data indicator than theoretical construct. The conceptual price paid for such operationalizing convenience may turn out to be steep indeed.

Having now reviewed some approaches to organizational goals what conclusions can we draw? First, goal positing predominates, especially among traditional international relations researchers, as a preferred mode of analysis because of its simplicity. Further, goal positing reflects a belief among many scholars that organizations, and especially nations, often have a set of "core" goals which are relatively impervious to change. The national core values idea posited by Holsti, the vital goals of Hartmann, and the general, absolute goals of Organski are all reflections of this belief.

Second, the notion of time has often either explicitly or implicitly played a significant role in goal conceptualization. Indeed, the view of goals as preferred, <u>future</u> end states implies some conception of time. Organski's long-range vs. immediate goal dichotomy, McGowan's use of difference equations implying a discrete time interval perspective, and the Richardson process equations, which assume a

continuous time perspective, are all examples of time's import in goal conceptualization.

Third, the search for suitable organizational goal conceptions has dovetailed with work on organizational structure (what Thorson has referred to as control structure[18]). Indeed, it is probably no accident that, while goals are used on many levels of analysis -- the international system, nation-state, and organizational-bureaucratic levels, goal conceptualization becomes increasingly more sophisticated as one moves down the ladder of abstraction, where goals are linked conceptually to organizational processing (as in the Thorson production systems approach) or organizational structure (as in the Simon "constraints set" or the Thompson dominant coalition approaches).

A fourth related point concerns the notion of subgoals. Since organizations aren't generally directed towards a single, overarching goal, conceptual approaches which can handle multiple goals, conflicting goals, and switches in goal priorities (i.e., redundancy of potential control) are especially valuable. Such conceptual concerns require close attention to *organizational* structure and processing -- attention which only Thorson's production system, Simon's "constraint set," and Thompson's dominant coalition perspective seem capable of. All the other approaches appear too abstract.

A final observation concerns the notion of a setting or environment within which goals are defined. Especially with the advent of the systems perspective, researchers have focused attention on external environments and their relationships to internal organizational structure. This sensitivity to environments is important because goals depend upon the interplay between organizations and environments, upon both organizational and environmental changes. From this standpoint, the blanket positing of universal goals, characteristic of early international relations work, is decidedly inadequate.

This brief literature review on goals has revealed important definitional trends involving time, organizational structure, subgoals, and environmental setting.

The following sections of this paper will examine these conceptual themes and their implications, arguing in the end, that any useful conceptualization or organizational goals cannot afford to neglect them; that, in short, goals are context dependent.

CRITERIA FOR GOAL-DIRECTED BEHAVIOR

Before moving further we should try to capture the intuitive features of goal-directed behavior by identifying and characterizing at least some of its criteria. Such criteria will provide a necessary background for the discussion in the following section on goal-directed systems.

Gerd Sommerhoff[19] has argued the essence of goal-directed behavior is flexibility; that is, any goal-directed entity must be capable of modifying its behavior in accordance with pertinent environmental charges. The problem here is capturing this flexibility in abstract terms.

Two conditions appear necessary if an entity's behavior is to be called goal-directed. First, the causal link between action and environment with respect to a goal must be brought about by the entity. In other words, the realization of a goal must depend, in some sense, on the entity's behavior. This condition excludes cases where the fulfillment of an effect is inevitable, independent of any considerations of an entity's goal or behavior. For example, under this condition and the perspective of modern physics, a shaman who recites an incantation each night to insure next morning's sunrise would not be exhibiting goal-directed behavior.

The second condition of goal-directed behavior concerns the coupling of an entity with its environment. The coupling must be such that changes in relevant features of the environment will induce entity behavior changes. In particular, goal-directed behavior demands the existence of feedback loops which register information about the environment, and, hence, the margin of error at which an entity stands at a given moment with respect to a given goal. Further, goal-directed

behavior requires some sort of internal processing capability (processing structure) which uses feedback signals to direct entity behavior. This internal processing structure incorporates within itself, by virtue of its design (e.g., the environmental variables monitored, the manipulable variables toward which behavior is directed), some abstracted image of the causal links in the entity's operating environment. For example, the behavior of a magnetic compass would qualify here as goal-directed behavior. The compass' magnetized needle provides both the feedback loop to the environment and the processing structure necessary for goal-directedness. For the compass, the environment is composed solely of magnetic lines of force. Environmental changes which do not disturb these force lines are irrelevant and have no influence on the compass' behavior. In general, if environmental changes do not alter the causal links upon which an entity's processing structure is based (i.e., the abstracted environmental image implied by the processing structure's mode of organizing and directing behavior), the entity will continue to goal-seek successfully. But, if environmental changes render an entity's environmental image inadequate, the entity will cease to exhibit goal-directed behavior. A compass placed within a strongly oscillating magnetic field, or a light-seeking mechanism placed in the dark will not goal-seek. Hence, an entity's ability to exhibit goal-directed behavior is not an innate trait, but depends on a given environment. A goal-directed entity in one environment needn't be goal-directed in another.

Further, goal-directed behavior, as specified above, cannot be unambiguously determined from observing entity behavior alone. Goal-directedness is dependent upon a particular description -- a description of an entity's internal processing structure, with all the causal assumptions imbedded in its image of the environment, and a description of the entity's environment relevant to the goal sought.[20] This description- or theory-dependent nature of goal-directed behavior can be elucidated by re-examining an example presented earlier. We noted a shaman, using incantations to insure each

mornings' sunrise, would not be exhibiting goal-directed behavior because some causal link must exist between his actions and his goal (i.e., causing the sun to rise). However, the existence or non-existence of such a causal link cannot be unequivocally proven -- it arises from current theoretical knowledge in astronomy. If later developments reveal a link between incantations and sunrises or if we adopt the shaman's image of the universe as a standard for evaluation, we would be forced to call the shaman's behavior goal-directed.

Further, if the analytical perspective used to assess the shaman's behavior were switched from astronomy to say, sociology, we might argue the incantations are directed towards preserving social cohesion in the face of nature's uncertainty. By spinning a socio-psychological narrative connecting the shaman's incantations with tribal psychology, we might reasonably conclude the shaman's behavior is indeed goal-directed with respect to social cohesion. The important point here is goal-directed behavior must be treated within some theoretical context if it is to be of any analytical use. The notion of goal-directed behavior, when devoid of theory, reduces to a metaphysical assumption. Hence, if a theorist wishes to speak of goal-directed behavior, he should specify those objects which give theoretical substance to the concept -- namely, a description of the goal-seeking entity's processing structure and the entity's operating environment. Unfortunately, as revealed in our earlier literature review, this theoretical completeness is often neglected, especially in the more traditionally based international relations research. As Thorson noted, in a related context:

> All too often, especially in theories expressed in natural languages such as English, the tendency is to assume that "everyone knows" what is being theorized about. Since "everyone knows," there is no need to specify explicitly what objects make up that world. Yet, it can be argued that theories are not about the world

but about "representations" of the world (or indeed, there may be many worlds), and it is useful to make public that representation by specifying it as unambiguously as possible.[21]

In fact, the most interesting disagreements in international relations spring from different theoretical reconstructions of posited, goal-directed behavior, suggesting the crucial importance in specifying clearly one's world representation or description.

Two final points about our criteria for goal-directed behavior: first, such behavior neither presupposes the eventual realization of the goal by the agent nor the contingent possibility of the goal's attainment. Hence, searches for nonexistent objects, such as an alchemist's search for the philosopher's stone, may very well qualify as goal-directed behavior, given a suitable theoretical framework or system of beliefs for evaluating the action under study. For example, suppose an astronomer searches for a nonexistent planet, which he believes exists. If the astronomer's theoretical framework is adopted as a standard of evaluation, then the astronomer is indeed exhibiting goal-directed behavior. If, however, some other, more advanced theory, which demonstrates the impossibility of the planet's existence, is used as a standard, then the astronomer's behavior must be adjudged nongoal-directed.

The second point about our criteria for goal-directed behavior is goal realization doesn't automatically imply goal-directed behavior. According to our two goal-directed criteria and current astronomical knowledge, our shaman would not be exhibiting goal-directed behavior however much we might envy his success record.

Having established general, abstract criteria for goal-directed behavior we can further sharpen this concept by considering three basic kinds of information upon which goal-directed behavior might depend.

Karl Deutsch has observed:

> A society or community that is to steer itself must continue to receive a full flow of 3 kinds of information: first, information about the world outside; second, information from the past, with a wide range of recall and recombination; and third, information about itself and its own parts.[22]

The first type of information cited by Deutsch, information about the environment, represents one of the necessary conditions introduced earlier characterizing goal-directed behavior. However, entities which are limited to this single source of information are often extremely inflexible. They depend solely on those environmental variables "designed" or "programmed" into their processing structure. Further, the inability to update this "environmental image" renders flexible, long-term operating perspectives impossible; hence, imparting a reflex action quality to entity behavior. The story of the spy, who wished to locate the seat of American power by trailing Pentagon telephone cables and, instead, discovered the Pentagon telephone exchange, is a humorous example of goal-directed behavior dependent solely on external environmental cues. A column of army ants, programmed by nature to respond to such a constrained set of environmental cues (i.e., the presence of other army ants) that it may lock itself in a circular "suicide mill" and continue circling to exhaustion, is another graphic example of the narrowness of goal-directed behavior dependent solely on immediate environmental information. Still another, more sophisticated example is the military's experimental missile guidance system called Terrain Contour Matching. Under this system a missile's processing structure is given a digital map of its flight path in terms of topographical features expressed in altitude values. While the missile is in flight, it scans the ground below, compares its findings with its

programmed course, and makes the necessary course adjustments. No updating in flight of the missile's digital map is possible, or really necessary because its operating environment, the terrain along its flight path, is, for all practical purposes, time-invariant. If, however, the terrain along the missile's path were to change significantly from its digital map values, the missile would be hopelessly lost. In general, because of the low level of sophistication displayed by such goal-seeking entities relying solely on environmental information, their heuristic value for studying international political phenomena is understandably modest.

Entity behavior guided by both environmental information and messages about changes in the entity's own internal processing structure represents the next level of potential capacity in goal-directed behavior. Devices which can monitor both their environments and internal structure have the potential of greater steering precision. Information on internal states might be used to control or even re-direct an entity's sensory devices, permitting greater flexibility and precision in the identification of environmental information gathered and processed in preference to others. Further, information on internal states can be used to protect an entity's processing structure, rendering it less vulnerable to threatening environmental variations or internal malfunctions. Entities with an automatic shutoff capability such as NASA's manned launch vehicles, which are programmed to shut off if any internal malfunction is detected prior to liftoff, are examples (in late 1965, during the Gemini-6 Mission, this automatic system was activated, aborting the launch).

However, entities with environmental and internal monitoring capabilities, like their less sophisticated, servomechanistic counterparts, suffer from a very narrow time perspective -- they have no capability for storing and retrieving past experience. The limitations imposed on goal-directed behavior unaided by a recall capability are

suggested by Frances Fitzgerald's description of the "timeless quality" characterizing Vietnamese pacification efforts -- the "Really New Life Hamlet" program (1967) superceding the "New Life Hamlet" program, which, earlier, had superceded the Strategic Hamlet program. "There was an archeology of pacification," Fitzgerald notes, "going back ten, sometimes twenty years. Many of the PF (Popular Forces) outposts . . . had been built by the French for the fathers of those same peasant soldiers."[23] She observes, "For those who stayed in Vietnam long enough, it was like standing on the ground and watching a carousel revolve."[24]

Goal-directed behavior, supported by a memory device (i.e., any facility which allows data from past experience to be stored and held available for recall and later processing[25]), potentially has a better chance of avoiding this "carousel effect" than goal-directed behavior unassisted by a memory capability. By enlarging an entity's data base beyond immediate information to encompass past experiences, memory devices provide a way by which an entity might avoid "endless loop" traps where unsuccessful behavior is continuously repeated. Hence, memory capability renders a goal-seeking entity less sensitive to immediate environmental variations. Of course, depending on the circumstances this can either be beneficial or detrimental. A memory capability would help an army ant colony avoid the endless circling of the "suicide mill," where we are implicitly assuming a relatively fixed environmental context. But, under changing environmental conditions, a memory may not always be beneficial.

The effectiveness of a memory capability depends on the frequency of memory updating and the stability of the relevant variables in an entity's operating environment. An entity in a relatively unchanging environment would need fewer memory updates, than one operating in an unstable one. Unfortunately, static environments don't characterize the world of international politics. International environmental contexts change -- often more frequently than organizations review and update their store of long-term operating principles. In such instances a memory capability can

be detrimental. For example, the legacy of the 1950's -- the Communist takeover of China, the Korean War, McCarthyism, Dulles' foreign policies -- has been convincingly invoked as the institutional "memory" which shaped, with disastrous consequences, U.S. Asian policy in the 1960's. Writes James Thomson:

> . . . in 1961 the U.S. government's East Asian establishment was undoubtedly the most rigid and doctrinaire of Washington's regional divisions in foreign affairs. This was especially true at the Department of State . . . It was a bureau that had been purged of its best China expertise, and of farsighted, dispassionate men, as a result of McCarthyism.[26]

A tentative conclusion, then, for goal-directed behavior augmented by a memory capability is that it represents a potentially more sophisticated mode of performance; but, that its actual value, like the notion of goal itself, is strongly context dependent.[27]

SUBGOALS AND DECISION-MAKING HIERARCHIES

Up to this point, we have established general criteria for goal-directed behavior. Further, we have identified some distinctions in goal-directed behavior based upon three kinds of information sources -- environmental, internal, and memory. These criteria were purposefully left abstract enough to embrace different definitional approaches toward goals (e.g., the production system approach, the constraint set approach, the dominant coalition perspective). The goal concept, because of its richness, admits a multiplicity of meanings; hence, at this juncture, it is perhaps more fruitful to treat goals indirectly through characterization, rather than by frontal, definitional assault. Moreover, definitional stipulation, without adequate background preparation, would risk the premature discouraging of future, more promising conceptual approaches towards goals.

Thus far, our discussion on goal-directed behavior has assumed a single goal, unitary entity approach. Under this perspective, such phenomena as multiple goals and switches in goal priorities (i.e., redundancy of potential control) are not readily manageable. Yet, intuitively, these phenomena appear to more accurately characterize the organizational problems of international politics than the single goal, serial processing nature of a servomechanism.

The additional conceptual structure needed to treat multiple goals and redundancy of potential control could, so contend a number of researchers, be provided by the notion of a hierarchy. J. Watkins, for example, argues a proper explanation of seemingly inconsistent behaviors requires the construction of a "hierarchy of dispositions," that is, a hierarchy of goals.[28] Herbert Simon sees hierarchies as the basic framework, the "architecture" of complex systems.[29] Further, preliminary modelling efforts using goal hierarchies have been carried out by Gordon Pask and by Bossel and Hughes.[30]

At the outset, two different hierarchical frameworks must be distinguished -- a hierarchical classification of "adaptive or purposive capability" and a hierarchy of decision-making units. The hierarchy of adaptive or purposive capability arises naturally from the consideration of two tasks which might confront a decision-making entity: goal-setting and goal-seeking. Goal-seeking merely refers to goal-directed behavior. Goal-setting refers to goal-directed behavior where goal changes are possible. Hence, by definition, any entity with a goal-setting capability also has a goal-seeking one. The adaptive capabilities displayed by an entity under various goal-setting and goal-seeking situations give us a rough indication of its decision-making "sophistication. This hierarchy of adaptive capabilities is shown in Table 1. Goal-setting and goal-seeking behavior is subdivided into different situations depending on whether the entity's environment, goal, and behavior remain stable or change. Under these criteria, four distinct goal-setting and four goal-seeking situations are identifiable.

Table 1. Hierarchy of adaptive capabilities

Goal-setting capabilities (goal-directed behavior where changes in goals are possible)

	Goal	Environment	Entity Behavior
1)	changing	stable	changing
2)	changing	changing	changing
3)	changing	changing	stable
4)	changing	stable	stable

Goal-seeking capabilities (goal-directed behavior)

	Goal	Environment	Entity Behavior
1)	fixed	stable	changing
2)	fixed	changing	changing
3)	fixed	changing	stable
4)	fixed	stable	stable < regulating behavior

The goal-setting and goal-seeking distinctions made in Table 1 are on a very high level of abstraction. Goal, environment, and entity behavior changes are all determined relative to some theoretical description which is here left unspecified. Such a description would specify those relevant variables (be they votes, temperature, torque, defense spending, velocity, osmotic pressure and the like) of theoretical interest under the particular analysis in question which define an entity's environment, goal, and behavior. Within this sort of implied framework of identified variables, the environmental, goal, and entity behavior changes in Table 1 refer to the addition or elimination of variables relative to an entity's operating capacity, and not necessarily to every change in a variable's value over time. For example, a temperature change from 75 degrees farenheit to 85 degrees farenheit would not constitute an environmental change for an ordinary home thermostat - i.e., the thermostat's environment over this change is stable. However, a temperature change from 75 degrees farenheit to 6000 degrees farenheit would qualify as an environmental

change since the molten remains of the thermostat would no longer be able to monitor temperature change. For all practical purposes, temperature could (at 6000 degrees F) be omitted as a variable relevant to the thermostat's operating capacity. Admittedly, this mode of specifying relevant environmental, goal, and entity behavior changes relative to a given theoretical description is fuzzy; however, the requirements of generality make further precision difficult. Given this understanding of change relative to environments, goals, and behaviors, we now consider some examples of goal-setting and goal-seeking.

Goal-setting clearly is the most sophisticated adaptive capability an entity can have, and is the least understood. No general theory of goal-setting exists. Nonetheless, at least three distinct goal-setting situations can be discerned, some of which are approximated by inanimate systems. The first situation (see Table 1) involves a stable environment where an entity's goal and behavior change. Political situations sensitive to the idiosyncrasies of wavering, uncertain elites serve as examples. The second goal-setting situation involves a changing environment in which an entity's goal and behavior change. Ackoff's hypothetical computer, programmed to play checkers and tic-tac-toe, and designed with a memory updating capability dependent on past games played might serve as an example. In this case, the playing styles of the computer's opponents and game switching between checkers and tic-tac-toe would represent environmental changes. The third goal-setting situation involves a changing environment, a corresponding change in an entity's goal, but unchanging behavior. A crude illustration might involve a nation which maintains a strong army for defensive purposes, then later finds all its external enemies have collapsed; but, nonetheless, continues to maintain its large army for internal domestic and economic reasons. Here, a particular behavior (maintaining a large army) remains unchanged despite environmental changes (disappearance of external enemies) and goal changes (the switch from a defensive military policy to an

internal security one). The fourth goal-setting situation entails a change in an entity's goal, but no changes in environment or behavior. A stylized example might involve a gambler at roulette who plays to win, then alters his goal and plays to lose. The gambler's goal switch, in this case, is accompanied neither by an environmental nor behavior change.

Unlike goal-setting, goal-seeking is a less complicated theoretical and design problem, since goal-seeking implies a goal has already been set in some fashion. Hence, each of the four goal-seeking situations in Table 1 can be illustrated using inanimate systems and devices. The first, goal-seeking situation involves a stable environment, a fixed goal, but changing entity behavior. A simple example would be a computer-controlled anti-aircraft system which fires shells at an incoming intruder, fails to down it within a certain time period, and then shifts to a more costly, heat-seeking missile system.[31] A possible, second goal-seeking situation involves a changing environment, a fixed goal, and changing entity behavior. A chess playing computer which modifies its playing on the basis of past games and which always seeks to win could serve as an example. A third goal-seeking situation entails a changing environment, a fixed goal, and unchanging behavior. A missile guided by radar, encountering chaff and then switching to infrared guidance serves as an example. The final, and perhaps simplest goal-seeking situation involves a stable environment, a fixed goal, and unchanging behavior. The regulating behavior of a thermostat falls into this category.

Up to this point, we have examined a hierarchical classification of adaptive capabilities, providing part of the framework which will enable us to treat subgoals. However, another concept of hierarchy, developed by Mesarovic,[32] is necessary for handling subgoals -- a hierarchy of decision-making units. This type of hierarchy requires: (1) the entity under analysis be decomposable into some sort of interacting family of subsystems; (2) all these subsystems exhibit goal-directed behavior; and (3) these subsystems be arranged hierarchically whereby some subsystems are influenced

or controlled by others. Again, like our earlier notions of environments, goal-directed behavior, and entity behavior, the concept of a decision-making hierarchy is description dependent. Its character and form depend upon the analytical intent and research interests of the researcher employing this hierarchical perspective.

Taking this notion of a decision-making hierarchy and relating it to our earlier discussion on adaptive capabilities provides a useful framework for discussing subgoals. Each subsystem in a decision-making hierarchy can be thought of as pursuing some goal (however a researcher chooses to define it), which can be considered a subgoal relative to the whole decision-making hierarchy. Moreover, in dealing with systems whose complexity requires hierarchical treatment, subgoals are likely to be of greater analytical use than a single, overall, composite goal representing the whole hierarchy because: (1) a composite goal, in order to capture all contingencies, is likely to be underspecified (e.g., survival, stability, and the like), or (2) if mathematically formulated, is likely to be of as much heuristic value as a specification of some large set, say a dictionary via enumeration.

Having established a decision-making hierarchy, our earlier adaptive hierarchy of capabilities encompassing possible goal-seeking and goal-setting situations can be applied to each subsystem. Hence, each subsystem can be viewed as engaging in some form of goal-setting or goal-seeking behavior. In this sense, the adaptive capability hierarchy is imbedded within the decision-making one. Further, the capability level of each subsystem relative to its subgoal is a rough indication of its "decision latitude." This notion of subsystem decision latitude, in turn, leads naturally to a discussion of the redundancy of potential control phenomenon.

The principle of redundancy of potential control refers, essentially, to the switching of command or control in a system from one location to another. Intuitively, four situations might exist to account for such control switching: (1) subsystems are, in some sense, competing for control over a number of events or

trials, and when a subsystem passes a certain information threshold in a given trial it commands until the next trial or event; (2) a single subsystem in a decision-making hierarchy may have the ability to "delegate" temporary control to other lower subsystems in the hierarchy; (3) a fixed, rotation or appointing procedure may exist; or (4) a subsystem may exercise control on its own initiative.

The first, "competitive" interpretation of control redundancy appears closely related to the notion of subsystem decision latitude; that is, the degree of adaptive capability enjoyed by a subsystem. A subsystem, for example, which is so severely constrained structurally, say because it lacks a memory capability, that it can goal-seek only under fixed conditions is likely to be far less successful in "competing" for control than a subsystem which can both goal-seek and goal-set. A political example of control redundancy under competition which stresses the importance of decision latitude concerns the Army's struggle over close air support missions. In the 1950's, the Army, believing the Air Force was neglecting combat support missions in favor of more glamorous strategic ones, began pushing vigorously for responsibility over close tactical air support roles involving helicopters and tactical transports. Eventually, the Army, aided by advances in helicopter technology and the Air Force's inability to satisfy Army needs won significant control over close ground support missions (the Army now has more pilots than the Air Force).[33] Another graphic example of the importance of decision latitude concerns the Navy's development of nuclear armed, carrier based aircraft. To sidestep Congressional and Air Force objections, the Navy simply developed a crude, low budget nuclear delivery system without approval. This fait accompli broke the Air Force's monopoly over nuclear weaponry, and guaranteed Naval control over seaborne nuclear delivery systems.[34]

The second, "delegative" interpretation of control redundancy, whereby a single high level subsystem delegates temporary control to a lower subsystem is illustrated by a naval fleet which follows the commands from the first ship to sight the enemy.[35]

Such authority is delegated by the fleet commander.

The third, "fixed rotation or appointment" interpretation of control redundancy refers to control shifts which are cyclically predetermined so all subsystems eventually have an opportunity to exercise control. A group of children who voluntarily take turns being captain of a baseball team or the rotating chairmanship of the Joint Chiefs of Staff serve as examples.

The fourth, "seizing the initiative," interpretation of control redundancy refers to control shifts arising from a subsystem's exercising of control on its own initiative. Churchill's unauthorized mobilization of the Royal Navy just prior to the outbreak of World War I is an example.

Besides the redundancy of potential control phenomenon, certain other features of subsystems in a decision-making hierarchy deserve mention.[36] First, a higher level subsystem in a decision-making hierarchy will probably have coordination tasks over lower levels, and hence, be concerned with a larger share of overall systems behavior. Moreover, such coordination tasks mean these higher level subsystems have longer decision periods than lower units. The reason -- they cannot act more often than those lower units being coordinated. This, in turn, implies memory capabilities are likely to be more sophisticated on higher rather than lower levels.

A second feature of decision-making hierarchies concerns environmental information. We earlier identified three possible information flows connected with goal-directed behavior: environmental, internal, and memory. The coordination responsibilities of upper decision-making units require a significant dependence on memory and internal monitoring capabilities. However, as Mesarovic notes, "The higher levels cannot respond to variations in the environment . . ., which are faster than the variations of concern to the lower levels, since the latter are reacting faster and more concerned with more particular, local changes."[37] This suggests lower level units, while perhaps endowed with little or no memory capability, are far more sensitive to environmental feedback than upper level units.[38]

A final observation on decision-making hierarchies concerns its possible use for coping with the analytical problem of goal-setting. We noted earlier no general theory of goal-setting exists. However, goal-setting might be conveniently handled by positing a suitable decision-making hierarchy whereby goal-setting on one level is a consequence of goal-seeking on a higher level. Hence, the problem of goal-setting on lower levels is side-stepped by invoking the goal-seeking processes on the next higher level. At the highest decision-making levels the goal-setting problem is avoided by simply positing goals. The justification for such positing comes from assuming: (1) the highest control levels deal with goals requiring long term decision times; (2) such long-range goals will, for a relatively long time span, elicit weak feedback; and (3) over this time span, the highest control levels can be analyzed in isolation without regarding feedback complications -- in particular, goals at these levels can be held constant.[39] Of course, this approach cannot treat goal-setting on all levels concurrently; however, this needn't discourage us. In general, no matter how elaborate any experimental design, certain simplifying assumptions must always be made. Of concern to us is the realism of our assumptions. Holding goals constant at the highest control levels of a decision-making hierarchy is such an assumption, with, as suggested above, much value.

TIME

The notion of goal-directed behavior implies certain things. It implies some entity, possessing an internal processing structure and feedback monitoring capability, to which goal-directed behavior can be imputed. It implies some environment in which the goal-directed behavior takes place. Finally, it implies some notion of time since goal-directed behavior, by its very nature, is concerned with some future state of affairs. Goal-directed entities and their corresponding environments have been treated above. Here, we consider some implications of time for the analysis of goal-directed behavior.

The temporal framework used to study goal-directed behavior can have profound analytical implications. It must be, in some as yet nonrigorously defined sense, appropriate to the phenomena studied. A motivating example demonstrating the importance of the "proper" conception of time arises from a paradox posed by the Greek philosopher, Zeno. According to Zeno's tale, Achilles and a tortise decide, one day, to have a race. Since Achilles can run twice as fast as the tortise, he generously gives the little animal a headstart of distance x. Now, in order to catch up with the tortise Achilles must cover this distance x. But in the time it takes Achilles to cover x, the tortise is moving also and has forged ahead a distance $\frac{x}{2}$. Achilles must cover this additional distance $\frac{x}{2}$ to catch up; however, in the time it takes Achilles to cover $\frac{x}{2}$, the tortise has again moved ahead by a distance $\frac{x}{4}$. In the next action sequence, Achilles covers $\frac{x}{4}$, but the tortise moves ahead again by $\frac{x}{8}$. Since this "catch up" process is a never-ending one, Zeno's conclusion is Achilles never passes the tortise!

The key to this puzzle lies in the way time is framed in the story. Each action sequence of the race, where the momentary positions of Achilles and the tortise are compared, can be thought of as a "snapshot" in time. The first snapshot at the race's beginning, pictures the tortise ahead of Achilles by a distance x, the tortise's headstart. Assume this snapshot is taken at time t. The next snapshot shows the tortise ahead of Achilles by a distance $\frac{x}{2}$. This second snapshot is taken at time $t + \frac{t}{2}$. The third snapshot is taken at time $t + \frac{t}{2} + \frac{t}{4}$, showing the tortise leading by a distance $\frac{x}{4}$. The fourth snapshot is taken at time $t + \frac{t}{2} + \frac{t}{4} + \frac{t}{8}$, the fifth one at time $t + \frac{t}{2} + \frac{t}{4} + \frac{t}{8} + \frac{t}{16}$, and so on. In short, the snapshots of the race are being taken at shorter and shorter time intervals, where the sum of these intervals is a converging, infinite series ($\sum_{i=0}^{\infty} \frac{t}{2^i} = 2t$). This snapshot sequencing, that is, the way time is being structured, prevents you from seeing Achilles catch the tortise, because an "infinite number" of snapshots

would be required. Hence, Zeno's paradox arises, it can be argued, because of the peculiar way time is structured in the story.

Several important lessons can be drawn from Zeno's story. First, time clearly poses an important conceptual challenge in studying goal-directed behavior. As demonstrated by Zeno's paradox, the way time is framed has crucial substantive implications which require close scrutiny. Another example drawn from international relations is Richardson's use of differential equations in his arms race work. These equations imply a continuous time perspective where nations are capable of continuous monitoring and adjustments in arms stocks. The realism of such an assumption is, given such complications as bureaucratic inertia, budgetary cycles, and lead times for weapons development, open to question.

Second, Zeno's story shows time needn't necessarily mean clock time, that is, a continuous flow of seconds, minutes, hours, days, years, and so forth. In fact, for analytical purposes, time is most usefully conceived of as *a mode of ordering events or observations*. This, in turn, implies time, like goals, is context-dependent and takes on meaning only with respect to a particular description of events. Further, for such a reference system, the time framework or event ordering selected can have a profound impact on the event patterns observed. In Zeno's story, for example, the infinite, converging time intervals ordering observations prevented us from seeing Achilles pass the tortise. If these time intervals had been equal, however, Zeno's paradox would have evaporated, and we would indeed have seen Achilles win the race. Hence, one's time framework must be appropriate, in some intuitive sense, to the research problem under analysis.

Clock time is sufficient for most research purposes; however, it is not always convenient. For example, studies on biorhythm (biological clocks) use physiological processes and cycles for event ordering. Geologists and paleontologists use geologic

time measured by decay rates of various radioactive isotopes. Economists sometimes find it useful to order events by fiscal years, economic five year plans, stages of economic growth (à la W. Rostow), and Kondratieff cycles. So far, most of these examples can be translated into clock time with little difficulty. However, this isn't always so. For example, international crisis research frequently uses the notion of response time -- a crisis is identified, in part, as a situation involving low response time for some decision-maker.[40] Unfortunately, response time cannot be equated with clock time because it implies more than temporal duration. First, response time depends on the decision-making skills and processes being studied. What might appear as a low response time situation for one decision-maker might be a high response time situation for another, more skillful one. Second, response time depends on the task being addressed. One hour might be a generous response time for a simple true-false history test, but miserly for a test in partial differential equations. The point here is clock time needn't always be convenient or even appropriate for all research problems.

Since clock time is not suitable in all cases, it is useful to examine other modes of ordering events, related to the structural properties of the phenomena being analyzed. In particular, when considering some entity's goal-directed behavior, *potential time frameworks*, can be drawn from two basic sources: (1) cycles within or related to the entity's internal processing structure; and (2) the environment's response cycles or patterns, if any, to the entity's behavior.

Often, time frameworks based on an entity's processing structure are conveniently represented by clock time. This is often true for entity's with simple internal processing structure or continuous processing capabilities (e.g., a thermostat). However, other time treatments such as event-based frameworks may be necessary for more involved entities and situations. For example, during the Second World War,

some Army Air Corps units automatically rotated bomber crews home after forty missions. Since the time necessary to complete these missions varied from unit to unit, air crews often conceptualized time in terms of missions flown, rather than months served.

Further, if the entity under analysis has a memory capability, the frequency of memory updating or alteration might be used to order events. Governmental upheavals due to elections, coups, purges and the like are some potentially useful examples of such organizational "memory alteration" which might serve as the basis for a time scheme.

The problem of selecting a suitable time framework based on processing structure becomes more complicated when dealing with a hierarchy of decision-making units. Here, suitable time frameworks must be found for all levels of the hierarchy with no guarantee these frameworks will be identical. This, in turn, can lead to problems of comparing different time frames. If, for example, one hierarchical level is best treated using a clock time scheme while another level demands an event-based time framework, the problem of relating these different time frames arises. Unfortunately, such conceptual problems have not yet, in general, been satisfactorily resolved.

Like time frameworks based on an entity's processing structure, those frameworks keying on environment response cycles are often conveniently represented by clock time. For example, after mailing an order to a company, we usually measure response time in terms of days, weeks, or months. In other situations, environment oriented time frameworks may require event-based treatments. A slot machine enthusiast, for example, might measure the length of his Las Vegas visit in terms of number of jackpots won. A more serious example concerns the inflationary spiral generated in 1966 by the Vietnam war. Thinking in terms of fiscal periods, government planners were stunned by the swiftness with which the economy overheated.

Major sectors of the economy, it now appears, roused by events in Vietnam and on Capitol hill, anticipated increased military spending and expanded their activities accordingly even before Federal spending actually penetrated the economy. In short, had the Johnson administration adopted an event time perspective, instead of one based on the fiscal year, timing of the Vietnam war's inflationary impact on the economy might have been more accurately estimated.

So far we have treated separately time frameworks based on entity processing structure and on environment responsiveness. However, it is worthwhile noting the implications of wide discrepancies, when comparison via clock time is possible, between time perspectives based on entity processing structure and environment responsiveness, since such discrepancies can have significant impact on international political theorizing. Before spinning out these implications, a few underlying assumptions will be aired.

First, it will be assumed the use of smaller time units encourages smaller analytical time horizons than the use of larger time units. For example, a person who orders his life's activities in terms of days will probably have a more circumscribed time horizon than one who thinks in terms of weeks or months. Second, it will be assumed the international environment in which nations operate is characterized by long-response times to foreign policy actions. This characteristic was highlighted by Dean Acheson's remark on carpentry as a nice hobby because one needn't wait twenty years to learn the results. Finally, it will be assumed international environmental response times are longer than the cyclic processing times of entity's operating in this international environment.

For cases where these assumptions are accurate, one would expect a time perspective based on entity processing cycles to employ smaller time units than one based on international environment responsiveness; hence, encouraging a smaller analytical time

horizon. A nice example is Daniel Ellsberg's argument that U.S. President's, over two decades, knowingly chose a stalemate policy in Vietnam. Ellsberg essentially keys on national elections, the internal processing cycle upon which his analytical time perspective depends, arguing all major escalatory decisions in Vietnam were constrained by the narrow time horizon imposed by election concerns. The result, Ellsberg contends, was a series of short-term, "no win -- no lose," holding actions.[41]

For cases where time perspectives are based on environmental responsiveness, one would expect relatively large time units and, hence, generous analytical time horizons. For example, the Jay Forrester world dynamics model[42] can be thought of as a simulation of environmental responsiveness to nation activities, which employs a longer time horizon than is customary in foreign policy analyses. Indeed, this discrepancy between the time horizon derived from an environmentally-based time framework and the smaller time horizon associated with national processing structures is the key to, what many believe is, the impending collapse of the global social and economic order. Nations, it is argued, tend assiduously to problems sharply localized in time while global disasters, unfolding within a larger temporal context, threaten to engulf everyone.

These examples hopefully demonstrate the theoretical importance of time frameworks for evaluating goal-directed behavior. Certainly, no single time framework is inherently superior. The appropriateness of a given time perspective must be judged on a case-by-case basis. Hence, full disclosure of temporal assumptions is important. In particular, an explicit conception of time must be a part of any theory of politics, especially if time is defined in terms of entity processing or environmental cycles. Only then can one's time framework be evaluated for its analytical appropriateness.

SUMMARY

We began our examination of the goal concept in international relations research by considering its role in theorizing. Goals and goal-directed behavior are working assumptions which reflect the posited regularity or underlying order of events in international relations upon which theorizing depends. Further, we identified two analytical strategies, posited preference and revealed preference, by which goal-directedness contributes to international relations theorizing.

After considering the analytical utility of goals, we briefly surveyed its past use in international relations research. While no consistent approach towards goals emerged from our survey, certain key themes and issues were discernible such as the linking of goals to organizational processing and structure, the notion of subgoals and switches in goal priorities, and the relationship of time to goals.

Next, to provide the necessary analytical background for treating these issues, we turned our efforts towards developing criteria for goal-directed behavior, avoiding the danger of prematurely specifying a single goal definition. It was then argued goal-directed behavior might be usefully characterized by two conditions: (1) some goal notion (left unspecified here) and attendant theory causally linking an entity's behavior and its goal, and (2) some feedback loop connecting the entity's processing structure to its environment. We further noted the potential advantages of goal-directed behavior backed by memory and internal monitoring capabilities.

Two notions of hierarchies, a hierarchy of adaptive capabilities and a hierarchy of decision-making units, were introduced. The hierarchy of adaptive capabilities aided us in distinguishing between different goal-setting and goal-seeking situations. The hierarchy of decision-making units provided a conceptual framework for discussing subgoals, the notion of redundancy of potential control, goal-setting, and goal-seeking.

Next, the problem of time was raised. First, we argued clock time isn't always analytically appropriate for treating goal-directed behavior. Second, in cases where clock time proves inappropriate, two alternative sources for structuring time were examined: (1) cycles or patterns related to an entity's internal processing structure, and (2) the environment's response cycles, if any, to the entity's behavior. Finally, the implications of differing time horizons arising from wide discrepancies between these two time perspectives were examined. Throughout this discussion, the context-dependent nature of time relative to the particular issue under study was stressed, thus re-emphasizing the description-dependent nature of goal-directed behavior in general.

FOOTNOTES

[1]William Riker and Peter Ordeshook An Introduction To Positive Political Theory (Englewood Cliffs, Prentice-Hall, Inc., 1973) p. 10

[2]John Gunnell "Social Science and Political Reality: The Problem of Explanation" Social Research, Vol. 35, No. 1 (Spring, 1968), p. 196.

[3]Herbert Simon The Sciences of the Artificial (Cambridge, MIT Press, 1969), p. 8.

[4]Riker and Ordeshook, p. 14.

[5]Graham Allison Essence of Decision (Boston, Little, Brown, and Co., 1971) p. 33.

[6]Ernst Haas and Allen Whiting Dynamics of International Relations (New York, McGraw-Hill, 1956), p. 59-69.

[7]Donald Puchala International Politics Today (New York, Dodd, Mead, 1971).

[8]See S.J. Thorson and R.A. Miller "Optimization and Arms Races: A Model Theoretic Analysis" (Columbus, Ohio State University, 1975) for an extended discussion of the theoretical implications of constructive specification. See also Mihajlo Mesarovic, "General Systems Theory and its Mathematical Foundation" (Case Western Reserve University, 1967).

[9]For an overview of research on international organizations, see Chadwick Alger "Research on Research: A Decade of Quantitative and Field Research on International Organizations," International Organization, Vol. XXIV, No. 3 (1970), pp. 414-450.

[10]Patrick McGowan "Toward A Dynamic Theory of Foreign Policy" (Syracuse, Maxwell School, Syracuse University, 1971). See also Patrick McGowan, "Adaptive Foreign Policy Behavior: An Empirical Approach" in James Rosenau (ed.) Comparing Foreign Policies (New York, SAGE Publications, Inc., 1974) pp. 45-54.

[11]The automatic, semi-automatic, and manually operated system questions on Kaplan's essential rules were initially raised by Inis Claude about Kaplan's "balance of power" system. However, such questions of interpretation can, in general, be lodged against all of Kaplan's models. See Morton Kaplan, System and Process In International Politics (New York, John Wiley & Sons, Inc., 1957), pp. 3-53. See also Inis Claude, Jr., Power and International Relations (New York, Random House, 1962), pp. 47-48.

[12]For discussions of the Parsonian approach to systems see Talcott Parsons, The Social System (New York, The Free Press, 1951); Structure and Process in Modern Societies (New York, The Free Press, 1960); and "An Outline of the Social System," in Parsons, et al., eds., Theories of Society (New York, The Free Press, 1961).

[13]For a more detailed treatment of production systems see Paul Anderson, "The Role of Complete Processing Models In Theories of Inter-Nation Behavior" (Ohio State University, Project for Theoretical Politics Research Report 28, 1974).

[14]As an interesting aside related to the production system's imbedded goal structure, Pask argues any system for which a cybernetic theory can be constructed must, of necessity, have some goal "built" into it. See Gordon Pask, "The Cybernetics of Behavior and Cognition Extending the Meaning of 'Goal'" Cybernetica, Vol. XIII, No. 3, 1970, p. 150.

[15]Herbert Simon "On the Concept of Organizational Goal" Administrative Science Quarterly, Vol. 9, No. 1 (June, 1964), pp. 1-22.

[16]James Thompson Organizations In Action (New York, McGraw-Hill, 1967), p. 128.

[17]Linda Brady "Goal Properties of Foreign Policy: Professed Orientation To Change and Goal Subject" (Vanderbilt University, CREON Project, 1974).

[18]Stuart Thorson "Modeling Control Structures For Complex Social Systems" (Ohio State University, Project for Theoretical Politics, 1974), pp. 3-6.

[19]Sommerhoff suggests three conditions for goal-directed behavior: (1) the goal pursued must be contingently possible, (2) system outputs or actions musn't be causally related by environmental variables; that is, the realization of goals must be achieved by the system, and (3) observed, goal-directed system behavior would have been appropriately modified to achieve the goal, if environmental conditions had differed from those actually observed.

The latter two conditions seem acceptable; but, the first condition, demanding contingent possibility, can be questioned. History abounds with explorers seeking nonexistent cities or continents (e.g., the Spanish search for the fabled Seven Cities of Cibola, the British search for a rumored southern Pacific continent, the search for a Northwest passage). Intuitively, one would like to call these searches goal-directed. Hence, in this paper, Sommerhoff's first contingent possibility condition is dropped. See Gerd Sommerhoff, Logic of the Living Brain (London, John Wiley & Sons, 1974), pp. 16-25.

[20]The relative, context dependent nature of purposes was clearly recognized by Rosenblueth and Wiener. They wrote:

> We believe . . . that the notion of purpose is not absolute, but relative; it admits degrees. We further believe that it involves a human element, namely the attitude and objective of the observer. Different observers may well differ in their evaluation of the degree of purposefulness of a given behavior. And the same observer may study a given behavior as purposeful or purposeless, with different objectives. But these limitations of the notion of purpose are common to many other scientific categories, and do not detract from their validity and usefulness. Arturo Rosenblueth and Norbert Wiener, "Purposeful and Non-Purposeful Behavior," in Modern Systems Research for the Behavioral Scientist, ed. by Walter Buckley (Chicago, Aldine Publishing Company, 1968), p. 235.

[21] Thorson, "Modeling Control Structures," p. 3.

[22] Karl Deutsch, The Nerves of Government (New York, The Free Press, 1966), p. 129.

[23] Frances Fitzgerald, Fire In the Lake (New York, Vintage Books, 1972), p. 453.

[24] Ibid., p. 453.

[25] As used here, a memory refers to the capacity for storing and retrieving past experiences which the entity has reacted to in some fashion. Data which has initially been "wired or designed" into an entity at inception as part of its processing structure would, therefore, not be considered a product of memory since this data did not arise from the entity's past operating experiences. So, for example, the digital map which is programmed before launch into the military's Terrain Contour Matching missile guidance system would not constitute a memory, as defined here.

[26] James Thomson "How Could Vietnam Happen? An Autopsy," in Readings In American Foreign Policy, ed. by M. Halperin and A. Kanter (Boston, Little, Brown and Company, 1973), p. 99.

[27] The context dependent nature of memory, and indeed of organization in general, also holds in a biological context as demonstrated by W. Ross Ashby:

> Is it not good that a brain should have memory? Not at all, I reply -- only when the environment is of a type in which the future often copies the past; should the future often be the inverse of the past, memory is actually disadvantageous. A well known example is given when the sewer rat faces the environmental system known as "pre-baiting." The naive rat is very suspicious, and takes strange food only in small quantities. If, however, wholesome food appears at some place for three days in succession, the sewer rat will learn, and on the fourth day will eat to repletion and die. The rat without memory, however, is as suspicious on the fourth day as on the first, and lives. Thus, in this environment, memory is positively disadvantageous. Prolonged contact with this environment will lead, other things being equal, to evolution in the direction of diminished memory-capacity.
> W. Ross Ashby, "Principles of the Self-Organizing System," in Modern Systems Research for the Behavioral Scientist, ed. by Walter Buckley (Chicago, Aldine Publishing Company, 1968), pp. 112-113.

[28] J.W.N. Watkins "Ideal Types and Historical Explanation," in The Philosophy of Social Explanation, ed. by Alan Ryan (Bristol, England, Oxford University Press, 1973), p. 101.

[29] Herbert Simon "The Sciences of the Artificial" (Cambridge, MIT Press, 1969), pp. 84-118.

[30] See Gordon Pask, "The Cybernetics of Behavior and Cognition Extending the Meaning of 'Goal'," Cybernetica, No. 4, Vol. XIII (1970), pp. 247-248. See also Hartmut H. Bossel and Barry Hughes, Simulation of Value-Controlled Decision-Making: Approach and Prototype (Karlsruhe, Federal Republic of Germany, Institut fur Systemtechnik und Innovationsforschung, August, 1973).

[31] Another, less militaristic example, cited by Ackoff, involves an electronic maze-solving rat (a simple automata) which, when blocked by a wall in maze, moves in a programmed sequence of ways until an open path is found. The sequence is such that it can solve at least some solvable mazes. If this rat has a memory device, it can also be programmed to take a "solution path" on subsequent trials in a familiar maze. See Russell Ackoff and Fred Emery, On Purposeful Systems (New York, Aldine-Atherton, 1972), p. 31.

[32] M.D. Mesarovic, D. Macko, and Y. Takahara Theory of Hierarchical, Multilevel, Systems (New York, Academic Press, 1970), pp.49-56.

[33] See Morton Halperin Bureaucratic Politics and Foreign Policy (Washington D.C., Brookings Institution, 1974), pp. 43-46.

[34] See Vincent Davis "The Development of a Capability to Deliver Nuclear Weapons by Carrier-Based Aircraft," in Readings In American Foreign Policy, ed. by M. Halperin and A. Kanter (Boston, Little, Brown, and Company, 1973), pp. 261-275.

[35] Thorson "Modelling Control Structures," p. 5.

[36] These characteristics are taken from Mesarovic. See Mesarovic, Macko, and Takahara, pp. 54-56.

[37] Ibid., p. 55.

[38] Stories of "men in the field" (i.e., lower level units of some decision-making hierarchy) who develop a greater sensitivity for their local areas than the people back at the "home office" (i.e., upper level units) are legion. More interesting are the tales of actual "memory suppression" on lower levels. Consider, for example, the plight of a military officer assigned to the Defense Intelligence Agency (DIA) during the Vietnam era:

> He knows or soon learns that he will be thrust into a position in which, on occasion, his professional judgment will vary markedly from that of his parent service. He will be expected to defend a position that could enrage his Chief of Staff -- but officers who do so more than once get known fast and are accorded an appropriate "reward" at a later date in terms of promotion and assignment. Consider also that a tour at DIA -- normally two to three years -- a very short when compared to a 20- to 30-year military career. And so most officers assigned to DIA go through a predictable pattern. They come on board as "hard-chargers," ready to set the world on fire. They stick to their principles through one or two scrapes. Then they become a little more circumspect, letting individual issues slide by and rationalizing that it wasn't a crunch question anyway. Finally, they resign themselves to "sweating out" their tours and playing every situation by ear. They avoid committing themselves or making decisions. They refuse to tackle the agency's long-term organizational ills, because doing so would make too many waves.

Patrick McGarvey, "DIA: Intelligence To Please," in Readings in American Foreign Policy, ed. by M. Halperin and A. Kanter (Boston, Little, Brown, and Company, 1973), p. 325.

[39]The assumptions listed here are derived from the work of Simon and Ando on decomposability and aggregation of systems. One of their theorems (as interpreted by Crecine) implies: if feedback is weak, there exists a time span over which a system can be analyzed in isolation without regarding feedback complications. The time span over which this analysis is valid depends on the weakness of the feedbacks. See J. Crecine, Governmental Problem-Solving: A Computer Simulation of Municipal Budgeting (Chicago, Rand McNally, 1969). See also A. Ando, F. Fisher, and H. Simon, Essays on the Structure of Social Science Models (Cambridge, MIT Press, 1963).

[40]James Robinson "Crisis: An Appraisal of Concepts and Theories," in International Crises: Insights From Behavioral Research, ed. by Charles Hermann (New York, The Free Press, 1972), pp. 23-25.

[41]Daniel Ellsberg Papers on the War (New York, Simon and Shuster, 1972), pp. 42-135.

[42]See Jay Forrester, World Dynamics (Cambridge, Wright-Allen Press, 1971).

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Governments as Information Processing Systems: A Computer Simulation*

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§ 1 INTRODUCTION

The purpose of this paper is to describe a computer simulation based project designed to elucidate the mechanism by which national governments obtain and process information about their environments and produce behaviors which are sent back to their environments. The procedure will then be to perform experiments on these simulations. More specifically, this report will discuss a preliminary version of a large scale simulation of Saudi Arabian decision making with respect to such domestic policy areas as oil, agriculture, and human resources. Following a treatment of the simulation in its present status, problems of evaluating, validating, and modifying the simulation will be examined. First however it is necessary to outline briefly the methodological perspective from which the simulations are being developed.

Within the field of international politics a number of scholars have begun to employ concepts rooted in "systems theory" to develop theories of governmental behavior (e.g., see Kaplan, 1957; Rosenau, 1970; Forrester, 1971; McGowan, 1974; Phillips, 1974; Thorson 1974a). Most all of these researchers comment on the relative "complexity" of international politics and the variety of difficulties this complexity poses for the theorist. As examples, it is likely that any reasonable theory would have to include a fairly large number of variables; that the relations between these variables may often not be simple linear ones; and that there are fairly long time delays operating with the international system. Such characteristics naturally suggest a computer simulation approach to the modeling of governmental decision-making.

While the above list of "complexities" is suggestive, it is nowhere near complete enough to restrict usefully the class of admissible models of governments. Yet the basic motivation behind any kind of experimentation - be it simulation based or otherwise - is to use prior knowledge. Quite obviously, the more detailed the prior knowledge, the more detailed will be the knowledge generated through a well-designed experiment. Equally obviously, it is generally easier to design optimal experiments (optimal here is being used in the sense of Fedorov, 1972) in situations where the store of relevant prior knowledge is large. A basic problem in macro-level modeling of governmental decision making is that available knowledge is neither detailed nor abundant.

The design of experiments must not only take into account available knowledge; it also requires a clear specification of the research question(s). At an abstract level two kinds of experiments can be distinguished. The first kind, sometimes termed "extremal experiments," is employed to answer questions concerning the conditions under which the structure being investigated will satisfy some optionality criterion. Thus it might be asked under what conditions a government will allocate its resources among domestic and international expenditures in such a way as to maximize some aggregate utility function. Elsewhere (Miller and Thorson, 1975a, b) it has been argued that not enough is yet known about governments to perform extremal experiments in a useful way. The reasoning behind this claim hinges on the dependence of most conditions of optimality (under most any usual sense of optimality) upon certain very finely grained (detailed) hypotheses (e.g., continuity, existence of second derivatives, etc.) being true of the world.

A second mode of experimentation has been called "mechanism-elucidating experiments" (Fedorov, 1972, pp. 3-6). Here the interest is more in the "global" behavior of the structure. That is, the task is to investigate implications of possible functional relations between input and output variables. Mechanism-elucidating experiments appear to be appropriate where existing theory is weak or nonexistent and where the purpose is to develop theory. The simulations reported on in this paper are being designed to be used in mechanism-elucidating experiments. Problems of validating such simulations will be discussed in a later section.

As was mentioned earlier, the design of any experiment derives from an attempt to exploit existing knowledge to suggest new knowledge. Therefore it is important to summarize the broad "operating characteristics" or "principles" which any structure posited as a possible model of a government must have. These properties may be viewed as properties necessary to any structure claimed to be a model of government. While the properties individually seem quite reasonable, there are few existing models which simultaneously satisfy all of them. Since these principles are discussed elsewhere, they will briefly be motivated and reference will be made to sources for further justification.

Even casual observers of politics are frequently struck with the changing and often apparently adaptive nature of national policy behaviors. International alliances seem to shift in apparent response to changing "realities" such as a perceived scarcity of oil. Yet, as with most all adaptive mechanisms, the range of adaptation has limits. Some policies (U.S. policy towards China would serve as an example) change very slowly and the reasons for the slow change seem related more to the internal structure of the mechanism itself (e.g., bureaucratic and individual level "politics") than to the external environment the government is attempting to handle.

Taken together, these observations suggest several principles. First, and of considerable importance, governments must be modeled as control structures operating in specific external environments. That is, governments attempt to manipulate specific external environments. No claim is made that governments are optimal control mechanisms. Further support for this claim can be found in Rosenau, 1970; Rosenau, 1974; and Thorson, 1974a. A well-known example of an attempt to model international behaviors without viewing governments as control structures is found in Forrester, 1971.

Second, the internal structure of the government must be explicitly modeled. In systems terms, the output of the governmental control structure will be a function (in the mathematical sense) of the inputs and the

current state of the government. There is considerable evidence to suggest that assessing the state of the governmental structure requires at least the modeling of bureaucratic structures within the government. Empirical support for this claim is found in Allison, 1971; Halperin and Kanter, 1973; and Halperin, 1974. Much of the arms race modeling effort (e.g., Brito, 1972) violates this principle and considers the government as a "unitary rational actor."

Third, internally governments are organized hierarchically. In other words, there is a large degree of specialization within a government. Different kinds of information and decisions are processed at different levels of the hierarchy. Support for this assertion is found in Phillips, 1974; Anderson, 1974; Mesarovic and Pestel, 1974; and Nurmi, 1974. Again, most arms race models and the Forrester WORLD2 model violate this principle.

Fourth, governments pursue multiple (and sometimes conflicting) goals. This principle is related to the previous principle, and support for it can be found in the same sources. While this claim seems most reasonable, there are some technical reasons (Miller and Thorson, 1975b) why this principle may need to be modified. Nonetheless, it has guided the modeling effort reported in this paper.

Fifth, governments exhibit redundancy of potential control. According to Arbib (1972, p. 17) the principle of redundancy of potential control "states, essentially, that command should pass to the region with the most important information." As an illustration Arbib (who attributes the example to Warren McCulloch) cites "a World War I naval fleet where the behavior of the whole fleet is controlled (at least temporarily) by the signals from whichever ship first sights the enemy, the point being that this ship need *not* be the flagship, in which command normally resides (p. 17)." The critical point here is that potential control need not reside in only one portion of a government. Indeed the way in which various governments resolve the redundancy is critical to understanding and explaining its behavior. Current attempts by the U.S. military to upgrade its command, control, and communications "systems" reflects an implicit recognition of the redundancy notion within one bureaucracy. Moreover, important decisions (e.g., whether to sell a sophisticated weapons system to some country) generally involve more than one bureaucracy at more than one level of the hierarchy. We could find no existing models which have the redundancy property.

Sixth, governments are event-based (that is, governments respond to events in the external environment). These events may have associated with them particular probability distributions. Thus long-range forecasting (though not policy planning) may be very difficult. Moreover the notion of time employed in the model should be "event time," that is, the "time flow" against which the system states are plotted should be event based. This suggests, for example, that differential equation models are either inappropriate or require considerable reinterpretation. The arms race models and the Forrester model are inconsistent with this principle. Crecine, 1969, provides evidence for the event-based nature of governmental structures. See Miller and Thorson, 1975b, for a more detailed discussion of this and the next point.

Seventh, models of governments must allow for disturbances. The environment in which governments operate is noisy, and random disturbances may be important in "defining" the events to which governments respond. The presence of disturbances is especially important to recognize if external experiments are to be designed.

The seven principles outlined above serve as framework conditions within which the simulation to be designed below is being developed. Basically, the domestic portion of the Saudi Arabia simulation is divided into three external environment models: an agriculture module, an oil module, and a human resources module. A fourth module, the decision module, serves as a model of the governmental control structure. These simulations are being developed in interaction with policy planners in the State and Defense Departments (see Phillips and Thorson, 1974 for a description of the interaction). In this paper the focus will be on the decision and the agriculture modules.

§ 2 OVERVIEW OF THE SIMULATION

Any attempt to model a government using a computer simulation must address two points: 1) What are the structural characteristics of a government; and 2) How is the structure to be implemented as a computer simulation? The first point deals with the nature of that which is simulated. The second, with its realization as a computer program.

The basic characterization used to structure the nature of governments is expressed in one of the organizing principles discussed above: Governments are goal seeking systems. But to simply state that governments are goal seeking systems does not provide sufficient structure to allow machine implementation. Additional structure is required. The additional structure imposed upon the characterizations of governments is illustrated in Figure 1. The basic elements of this structure are: 1) the government (or inner environment); 2) the outer environment (the process to be controled); 3) the observation interface; 4) the access interface; and 5) the model of the outer environment. (Cf. Simon, 1969; Thorson, 1974). Under this interpretation, governments take observations of the current state of the outer environment. Based upon those observations, the government, with the use of the image of the causal operation of the outer environment, generates outputs (access interface actions) that are intended to increase the level of goal achievement.

In the Saudi Arabian simulation presented here, the inner environment, access interface, and observation interface are all parts of the Saudi bureaucracy. The environment can be usefully partitioned into two classes, the domestic and international environments. In the simulation, the domestic environment has been additionally decomposed into three sectors: oil, agriculture, and human resources. Each of these three components are simulations in their own rights. The oil module models oil production and petroleum revenue, the agriculture module models the production of wheat, and human resources models the flow of people in Saudi Arabia from the perspective of education and employment. Thus on one level, the decision module attempts to control these three domestic environments so as to achieve a set of goals. In addition, the government of Saudi Arabia has goals for the international environment. The entities in the international environment consists of other nations, e.g., Iran, Egypt, Israel, the United States, governmental organizations, e.g., OPEC, the Arab League, the PLO, and the UN, as well as non-governmental actors, e.g., ARAMCO. In this report, the only portion of the simulation to be discussed in any depth will be the agriculture module (the environment) and the portion of the decision module with primary responsibility for controlling it (the Saudi Ministry of Agriculture).

Even with a characterization of that which is to be simulated, and the organizing principles constraining admissable solutions, there is still the question of imple-

mentation. Since the construction of the simulation is an effort at elucidating the internal mechanism by which governments generate behaviors, the manner in which the model is represented as a computer program is consequential. In the area of computer simulations of human problem solving, similar concerns have been expressed. Allen Newell (1973a) developed the notion of control structure as a means for addressing this point. The control structure of a model is roughly the system architecture. The control structure specifies how the basic processes of the model are organized into a coherent whole. The control structure is in part determined by the programming language used.

> A language such as FORTRAN (or any other, for that matter) may be seen as a device to evoke a sequence of primitive operations, the exact sequence being conditional upon the data. The primitive operations in FORTRAN are the arithmetic operations, the given functions ..., the assignment of a value to a variable, the input and output operations, etc. Each of these has a name in the language (+, -, SIN, LOG, etc.). However, just having the names is not enough. Specifying the conditional sequence is also required and what does that is called the control structure. In FORTRAN it includes the syntax of algebraic expressions, ... the order of statements,... the syntax of the iteration statement, ... the format of the conditional and unconditional branch. (Newell, 1973b 297)

For some purposes, it is acceptable to let the programming language determine in large part the control structure. Other times contraints such as minimum execution time, or minimum storage requirements will help determine how the control structure is realized. But if one wishes to make a theoretical statement using the structure of the program itself, those solutions are not acceptable, since such solutions contain implicit but inadmissable theoretical claims. The programming technique (and control structure) that is used for the decision module is called a production system. Since the intent is only to theorize about governments, PL/1 has been used for programming the oil, agriculture, and human resources simulation module. Newell developed this programming structure for the simulation of cognitive processes. While the operation of production systems will be discussed in more detail below, several comments are in order. The first is that all operators, other than the basic flow of control in production systems must be explicitly defined. Second, programs structured as production systems do not result in the minimization of program coding time, execution time, or storage requirements. There exist "easier" methods for coding a program to produce similar outputs. But these other ways to program the decision module have the potential for introducing methods and processes that do not reasonably reflect the structure or capability of the processing mechanism of governments. Given the basic flow of control inherent in production systems, it was necessary to define only one additional operator, the ** operator discussed below. This method for structuring the decision module has the advantage that the claims about the information processing capability of governments are explicit. Any assumptions about the capability of governments to process information had to be explicitly defined. Thus the chance of making unintentional capability claims as a result of the way in which the decision module was programmed have been minimized.

Processing models written as production systems are formed by a collection of independent rules, called productions. The rules (or productions) are stated in the form of a condition and an action: C → A. The condition refers to the symbol in the short-term image (STI) of the system. The STI represents the system's transient image of the current state of the OE. The actions of the productions consists of transformations on the STI "including the generation, interpretation, and satisfaction of goals, modification of existing elements, and addition of new ones." (Klahr, 1973:528) A production system obeys simple operating rules:

i. The productions are considered in sequence, starting with the first.
ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in STI. If all of the elements in a condition can be matched with elements (in any order) in STI, then the condition is satisfied.
iii. If a condition is not satisfied, the next production rule , the ordered list of production rules, is considered.
iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).
v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.
vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.
vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost. (from Klahr 1973:528-29)

Prior to a discussion of the production system for the Saudi Ministry of Agriculture in detail, the basic operation of the module will be discussed. After the operation of the system has been discussed in a verbal fashion, a portion of the production system will be discussed in detail as a production system.

As discussed above, a number of organizing principles have been employed as constraints on admissable solution to the construction of a simulated government. Not all of those principles are directly reflected in that aspect of the decision module which roughly corresponds to the Saudi Arabian Ministry of Agriculture presented here for several reasons. In particular, the principles of hierarchical organization, redundancy of potential control, and multi-goal seeking are not represented because the simulation module as represented here is only a portion of the total structure. In addition, since the decision module is a developmental version, the decision making properties of the module are at a relatively primitive state. In spite of these shortcomings, the module, as presented above, does serve as a useful illustration of the basic technique and its potential.

In essense, the decision module can be conceptualized as attempting to improve performance as indexed by a function with two arguments: yield = f(fertilizer constraint on yield, mechanization constraint on yield). Within the agriculture module, the yield at any given point in time is a function of the level of fertilizer application and mechanization usage. The fertilizer constraint on yield can be expressed as follows: given the current level of fertilization, assuming all other factors are optimal, what is the maximum possible yield? The mechanization constraint has a similar expression. Since the actual yield will be constrained by the smallest constraint, if yield is to be increased, the lesser of the two constraints must be increased. The policy

variables open to the government, under this interpretation, are the amount budgeted for governmental fertilizer purchase, and the amount budgeted for governmental provision of tractors.

Assuming that the Saudi's budget is increasing, the motivation for the resultant governmental output is as follows: Assume there is more money to spend, the constraint is (say) fertilizer, and the desire is to raise yield. More money should be spent on fertilizer and the same amount on mechanization. Mechanization could be decreased since some money spent on mechanization is wasted, but since it is not known exactly how the mechanization constraint behaves with respect to budget levels and since money is "cheap" and decreased yields are "costly" it is more prudent to take the chance of "wasting" some money by spending more on fertilizer to improve the chance of increasing yield.

From a more operational perspective, it is required that governments make observations of the environment and base outputs upon those "perceptions" of the current state of the outer environment. As a result, inputs into the decision module are statements describing the current mechanization and fertilizer constraints on yield as being very high, high, moderate, low, and very low. These descriptions of the constraints are determined according to the scale in Figure 2. An inspection of Figure 2 shows the scale not to be an equal interval scale. Judgments between high and very high represent finer distinctions than does a judgment between high and moderate. This scale and the use of an ordinal description of the outer environment is based on two assumptions: The first is that the Saudi government does not have the information processing capacity to handle (nor the measurement sophistication to use) finer distinctions. The second is that the Saudi's are capable of making relatively finer distinctions at the extremes of the scale. This claim about the capability of the Saudi's to process information is supported by by Al-Awaji's (1971:147) description of the planning system as "institutionally fragmented and substantially ineffective," the lack of qualified manpower to staff the Saudi bureaucracy (Al Awaji, 1971:218), and the fact that as of today, there still has not been a thorough census of the Saudi population.

Based upon the absolute judgments of the constraints, the decision module makes a comparison between the two constraints, resulting in relative statements such as: "The fertilizer constraint is much greater than the mechanization constraint." This comparison is also based upon the scale in Figure 2 and reflects the fact that judgments are more fine grained at the extremes of the scale. One constraint is higher than another if a "boundary," i.e., the cutoff point between high and medium, is crossed. For example, a very high constraint is judged greater than a high constraint, and a high constraint is judged greater than a medium constraint. If two "boundaries" are crossed, the comparison is that of very high. Thus, a very high constraint is very much greater than a medium constraint, and a medium constraint is very much higher than a very low constraint. If more than two boundaries are crossed, the comparison is 'much greater than'.

These two rankings of the constraints serve as the basic input to the choice portion of the production system. The structure of the decision module breaks the process of generating outputs into two portions. First the budget to be manipulated is determined, e.g., budget for fertilizer purchase, and/or budget for tractor purchase. Secondly, the amount of change in the budget's selected (increase a little, increase, increase a lot) is determined. The decision module uses the first relative judgment (greater than) to determine which budget to manipulate. If one constraint is less than the other, the lowest constraint is chosen. If both constraints are "about the same," both budgets are increased. If the budget to be increased has a high or very high constraint, the budget is increased "a little." If the constraint is medium, the budget (or budgets) is simply "increased." If the level of the constraint is low or very low, the budget is increased "a lot."

In the current implementation of the decision modul increase a little means to increase the budget by 20%, increase means increase the budget by 50%, and increase a lot means to increase the budget by 150%. Since the actual budget changes will in the final analysis be determined by the Council of Ministers, the current procedure represents only a temporary method for allowing a portion of the decision module to operate for testing purposes. The rates of increase should not be taken too seriously. In addition, the portion of the module discussed above assumes no budget decrease takes place.

A Production System Example

In light of the above discussion of the rules upon which a production system operates, and the non-technical (from a programming point of view) discussion of the operation of the module, the portion of the agriculture module in Figure 3 should be fairly straight forward. The system in Figure 3 is that portion of the production system that takes the judgments of the size of the constraints and determines which budgets to increase and by how much they should be increased.

As mentioned above, there is only one operator that was implemented, the ** operator. The ** operator takes the first element in the short term image (STI) and replaces it with the double stars. Thus, if the ** expression were: OLD(**) and the first element in the STI where $$$$$, then after the execution of the **, the front of STI would be: OLD($$$$$). This operator was necessary to insure that the system would not go into an endless loop. If a production were satisfied by the elements of STI, after the operation of the ** operator, the production would not be executed again, until the masked condition were reentered into STI.

As an example, consider the operation when the STI contains the symbols YMECH MEDIUM,YFERT GREATER THAN YMECH. The system starts with production 1. Since the conditions of production 1 are not in STI, the system checks production 2. This process continues until production 12 is executed. The elements in STI match the conditions of the production, and the action portion of the production is executed. This results in 1) the elements in STI that matched the production conditions being placed in the front of STI; 2) the ** operator is applied to the first element in STI, YFERT GREATER THAN YMECH. The result is that OLD(YFERT GREATER THAN YMECH) is now the first element in STI; 3) the symbol string INCREASE BMECH A LOT is placed in the front of STI, moving all other symbol strings down one position; 4) control is passed to the first production. The system loops through the productions until none of the productions is satisfied. At that point control passes to the portion of the module responsible for taking these qualitative changes in the budgets and producing actual budget figures.

The agriculture decision module presented here serves only as a preliminary version upon which more sophisticated and reasonable modules can be based. Besides the obvious necessity of addressing the question of the validity of the simulations (discussed below), the next path for future development are in two main

-as. The first is the development of the processing sophistication of the decision module; for example the necessity to model learning within the bureaucracy. But in its present form, no learning takes place in the decision module. In addition, the implicit model of the environment the module is attempting to control is made up of monotonically increasing functions. For example, the decision module implicitly assumes that the yield function always increases with increased levels of the relevant variables. Thus, from the perspective of the decision module, if 2 kilograms of fertilizer per hectare are good, 200000 kilograms of fertilizer will result in even better yields. The second class of sophistication that is planned for the decision module is that of language processing. The quality of language processing becomes especially important when dealing with the international aspects of the outer environment. Diplomacy is in many respects a linguistic exercise. The capability for language processing entails that outputs from the simulations be sentences in a language. For the simulation to have this capability, several things are necessary. First the language and its associated grammar must be specified. Secondly, the routines must be written which will take sentences describing either states of the environment or actions of other actors as input and produce perceptions of the current level of goal achievement to serve as inputs into the decision making portion of the system.

§ 3 VALIDATION

Since a simulation approach was adopted out of a concern for explicitly modeling the complexity of international politics, the validity of the simulation is very difficult to assess. Nonetheless, it seems clear (at least in a "lessons learned" sense) that large scale social simulation efforts must be continually concerned with validity issues (e.g., see Brewer, 1974). The discussion of validation problems provided in Hermann, (1967) is a very useful summary of the issues involved. Rather than repeat his points, this discussion will focus on problems specific to the "production system" approach described above and to the concern for doing mechanism elucidating experiments. If the research questions necessitated (and at some point they will) extremal experiments, then it would be critical to consider the problem of construct validity much more than has been done thus far. Ideally, each variable in the simulation would have several converging measures or indicies. If observed values of a particular measure of a certain variable can be used to predict to observed values of other measures of the same variable, confidence is increased that the variable is being measured in a valid manner. For example, if the output of the agriculture module is operationalized as (1) reported number of bushels of wheat per acre, and as (2) reported number of bushels of corn per acre, the output construct is validated if both measures increase concordantly. If they do not, the definitions are not converging and therefore one or the other or both are not valid.

A second criterion important for evaluating simulations used in extremal experiments is the "precise" correspondence between the hypothesized relations among the variables in the simulation and those in the system being simulated. If the agriculture module hypothesizes that agricultural output will increase when the number of tractors is increased, then once both variables are defined, the correlated increases must be demonstrated to occur. Both construct validity and "hypothesis validity" are critically important to establish prior to doing extremal experiments since such experiments assume that both the variables are being measured "well" and that the functional form relating the variables is known (see Fedorov, 1972, p. 6). However, for the reasons outlined in §1 the simulation reported on here is viewed more as aiding in elucidating more macro-level or global attributes and behaviors. As a result there are several validity issues which must be resolved prior to extensive consideration of construct and hypothesis validity questions.

It was argued in §1 that it was necessary to model the internal structure of the government. Thus (using the language of Zeigler, 1970) the desire is not only to establish an input-output morphism between the production systems and the Saudi government but also to preserve certain internal processing relations intervening between inputs and outputs. Measures must therefore be established for bureaucratic variables as well as for external environment variables. For example, bureaucracies in the Middle East vary in their sophistication, and level of trained personnel. Thus their information processing capabilities also vary.

Moreover since the simulation hopefully will be developed from its present primitive state to a more "sophisticated" form, there is no point in applying very strict operational tests to the relations when fairly crude observations are sufficient to suggest needed restructuring. For example, King Faisal is a dominant force in Saudi Arabia, yet his impact has yet to be included. In addition, the agriculture process model completely ignores the role of labor. That is, yield is independent of the number of farmers. Nonetheless, it seems reasonable to require that the simulations be continually monitored in order to ensure a satisfactory final product. Fitting the evaluational criteria to the purpose of the simulation at various stages in its development is consistent with such monitoring. More specifically, the different modules are in different stages of development. For example, thorough defining of converging measures of variables and statistical comparison of postulated with observed relationships among values on the variables is appropriate for evaluation of portions of the agriculture, human resources and oil production modules. That there is a positive correlation between number of tractors purchased and number of bushels of wheat produced is already directly testable. But for the decision module, and for other aspects of the external environment modules, these procedures would be premature. There are at least two important reasons for this claim. First, for examining the output behavior of the decision module, a sophisticated description of the environment upon which it must act is required. Such a description is not yet available. Second, for evaluation of relationships the exact functional form relating variables must be specified. Currently work is still underway examining various possible forms and it is not yet clear just what the most satisfactory form of these functions should be.

Clearly, however, aspects of the module are amenable to other forms of evaluation even at its early stage of development. Townsend (1972) in comparing psychological information-processing models, suggests that the limits of what responses the models can produce is an important place to start in evaluating the models. This can be done at the simulation level only or at both a theoretical and an empirical level. For example, in the agriculture decision module, the amount of fertilization and number of tractors are constrained so that if one increases the other must also increase or remain stable. Whether such a constraint holds empirically is a question that can be investigated.

A second aspect of the simulation which can be evaluated is the degree to which it includes variables which are clearly relevant to the operations it is car-

rying out. Especially at an early stage of development such questions are crucial to ask of the simulation. For example, the oil production module takes only two inputs, budget for exploration and production. Perhaps skilled labor is also important for determining final production level.

One valuable source of information about what variables ought be included has proven to be policy planners in the State and Defense Departments. These people are actively involved in monitoring the processes being simulated and, as a result, have formed "mental images" of these processes. Initial interviews were conducted to introduce ourselves and our goals to policy planners and to elicit from them their idea of key variables and the relationships between these variables. The overall intent of the interviews was to identify images in the areas of system identification, controls, and outputs. Interviews were performed in the Department of Defense's International Security Affairs and the State Department's Intelligence Research Groups. Subsequently, interviews have been held in the Defense Department's Policy Analysis and Evaluation Agency.

Initial interviews coupled with a preliminary analysis of relevant academic literature in the areas of oil production, agricultural economics and human resource economics produced initial flow diagrams. These flow diagrams were used to generate responses, in terms of agreement or disagreement with the relationships demarcated, from the interviewees. Several of those interviewed responded with helpful suggestions. Unfortunately most of those interviewed (not surprisingly) found the flow diagrams difficult to work with or were reluctant to comment until they could assess what the relationships led to in terms of specific output. Thus current evaluation efforts in part on letting the policy planners interact with the operating simulations.

The above considerations, then, are central to evaluational monitoring of the Saudi Arabia simulation. The last part of this section of the paper will attempt to take an additional step toward evaluation of what remains the most problematical aspect of the simulation - the decision module. The difficulty in evaluating the module concerns possibilities for defining appropriate measures for the variables contained in the module. Two possibilities which may yield a considerable payoff will be discussed.

A first possibility lies in taking an event data approach to defining variables. As described by Burgess and Lawton (1972) this approach defines categories of communications (the "events") and then treats them quantitatively. For example, common event categories for action include diplomatic protest, give warning, protest, and break diplomatic relations. The event data analysis is potentially advantageous to simulations such as the one described here because it does allow quantification of aggregate behaviors. Existent event data are, unfortunately, probably not directly usable in the Saudi Arabia simulation because, first, no one has collected data on all or even many of the events directly relevant to the simulation. Secondly, it is hypothesized in the simulation that information is processed in a culturally dependent way. This means that the access interface of the module itself must determine the coding strategy for identifying and categorizing events. Finally, much of the event data analyses currently available use categories which are too gross for what is needed in the decision module. As was argued in §1, a minimal unit of analysis appears to be the bureaucracy. Once the level of analysis in events data is established, and the events categorized, it is impossible to regain a finer-grained level of information. In spite of these problems, the events data approach seems a potentially fruitful one to try, in that it does allow the abstracting of behavioral occurrences into a usable quantitative form.

A second possibility for measuring variables in the decision module hinges on the module's observation interface with the external environment. The interface operates on the external environment, e.g., the two constraints and their qualitative measurement discussed above, producing a filtered "picture" for the decision module. This process can be indexed by comparing, for example, New York Times descriptions of events to reported perceptions or those same events by Saudi officials and in Saudi technical reports. Once the events data analysis has allowed categorization of Times descriptions, they can be compared to event data analyses of reported perceptions inside Saudi Arabia.

Before event data descriptions can be usefully employed, the language processing capabilities of the simulation discussed above must be implemented. Once the basic language has been specified, the resultant taxonomy of events will allow event descriptions to be coded into the language of the simulation for comparison. In addition, the outputs from the decision module (sentences in the language) can be coded according to existing event data coding schemes. Thus while current event data collection efforts are not directly relevant, the simulation outputs can be made comparable to existing data collections.

In addition to the general problems of validity, there are three questions that pertain to validity that can be asked of the structure of the decision module for the Saudi Ministry of Agriculture. The first is: Does the production system faithfully reflect the manner in which the Saudi's process information about the environment? In the production system illustrated above, this question has several implications. It is the case that the Saudi's make the sorts of distinctions about the information they received that the model assumes that they do? In the production system, an explicit scale is used to represent knowledge about the environment. Additionally, the production system invokes an explicit model of how the environment will respond to various decision module outputs, e.g., levels of the various budgets. The second question is: Are the descriptions of the environment in the decision module consistent with those that the Saudi's use to describe the environment? For example in the decision module, the two variables upon which the description of the environment are based are the fertilizer and mechanization constraints. The third question is: Are the information capabilities assumed for the decision model consistent with the capabilities of the Saudi's? In other words, do the Saudi's have the capability to determine the fertilizer and mechanization constraints. Given that the Saudi do not currently have the bureaucratic ability to determine the population, it may not be reasonable to assume that the bureaucracy has the capability to perceive these two constraints.

§ 4 SUMMARY

While the arguments presented in this paper do not really settle any substantive issues, they do suggest a strategy for doing simulation based research on the behavior of nations. First, a number of basic principles which must be satisfied by any structure claiming to be admissible to the class of governments were identified. Problems in implementing these principles in a computer simulation were then discussed. Specifically it was argued that governmental bureaucracies be modeled as production systems (linearly ordered lists of "condition → action statements"). Such an approach requires that the modeler pay close attention to the way information is

processed within the bureaucracies. This approach was illustrated by operating production system modeling the control of agriculture in Saudi Arabia. The final section discussed problems in validating the computer simulation and proposed the sorts of analyses necessary to a more thorough evaluation.

ACKNOWLEDGEMENT

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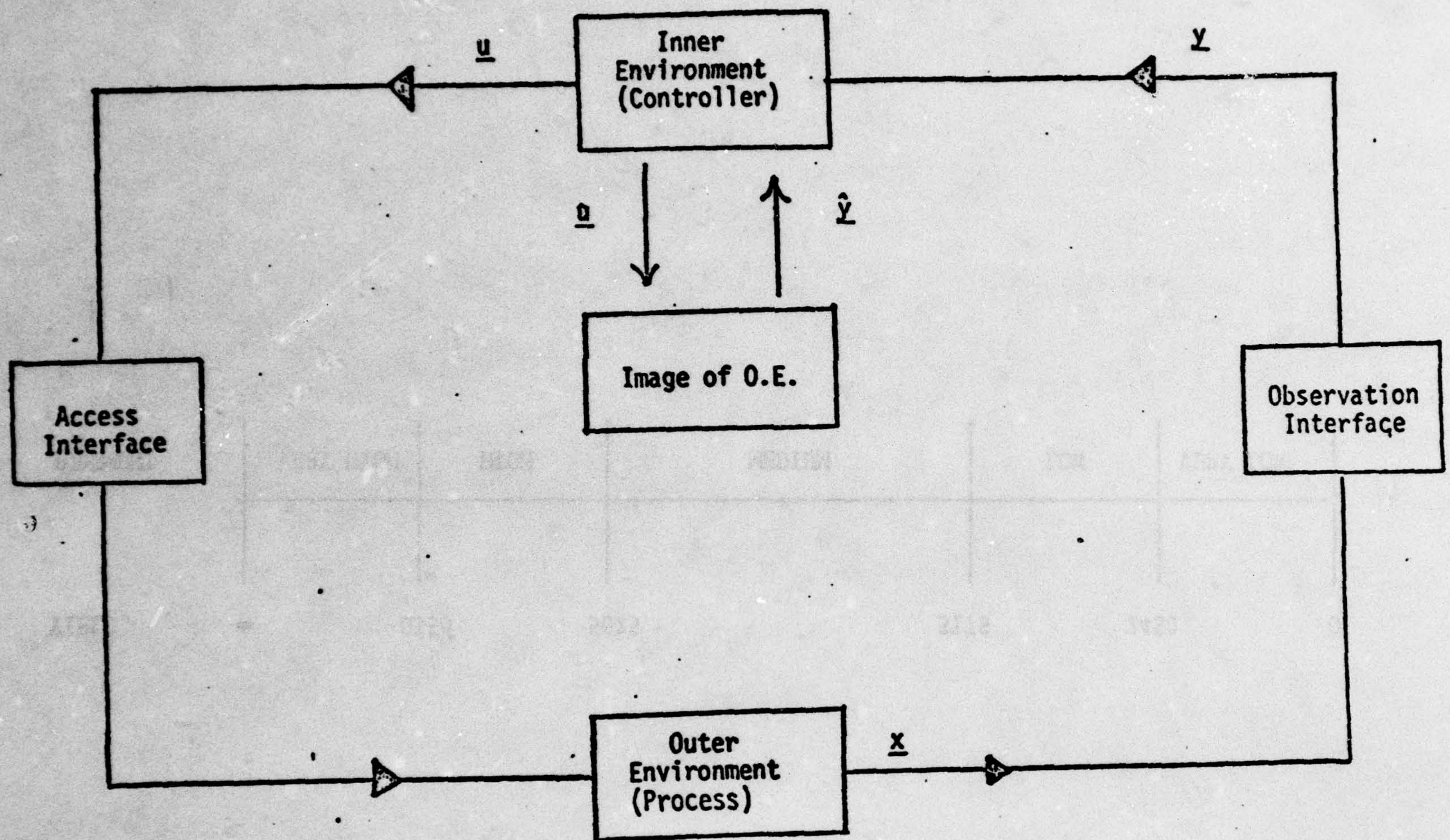
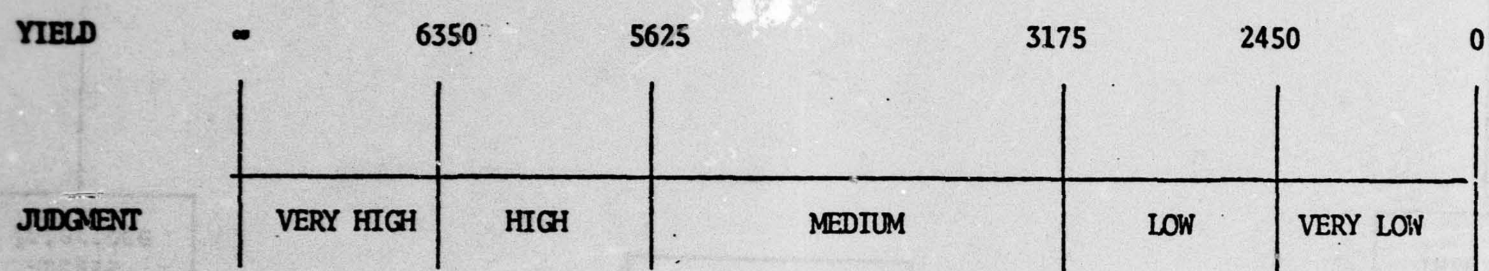
Figure 1 Artificial System Structure

Figure 2 Constraint Judgment Scale

Figure 3 A Partial Agricultural Production System



Inner Environment (Controller)
Image of O.E.
Observation Interface
Access Interface
Outer Environment (Process)
u
y
û
ŷ
x


YIELD
∞
6350
5625
3175
2450
0
JUDGMENT
VERY HIGH
HIGH
MEDIUM
LOW
VERY LOW

```
P1  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH LOW)
    Actionn   (OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)

P2  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH VERY LOW)
    Action    (OLD (**), INCREASE BMECH A LOT, INCREASE BFERT A LOT)

P3  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH HIGH)
    Action    (OLD (**) INCREASE BMECH A LITTLE, INCREASE BFERT A LOT)

P4  Condition (YMECH ABOUT EQUAL TO YFERT, YMECH VERY HIGH)
    Action    (OLD (**),INCREASE BMECH A LITTLE, INCREASE BFERT A LITTLE)

P5  Condition (YMECH GREATER YFERT, YFERT VERY LOW)
    Action    (OLD (**), INCREASE BFERT A LOT)

P6  Condition (YMECH GREATER YFERT, YFERT LOW)
    Action    (OLD (**), INCREASE BFERT A LOT)

P7  Condition (YMECH GREATER YFERT, YMECH HIGH)
    Action    (OLD (**), INCREASE BFERT)

P8  Condition (YFERT GREATER YMECH, YMECH LOW)
    Action    (OLD (**), INCREASE BMECH A LOT)

P9  Condition (YFERT GREATER YMECH, YMECH VERY LOW)
    Action    (OLD (**), INCREASE BMECH A LOT)

P10 Condition (YFERT GREATER YMECH, YFERT HIGH, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH)

P11 Condition (YMECH GREATER YFERT, YMECH MEDIUM, YFERT VERY HIGH)
    Action    (OLD (**), INCREASE BMECH A LOT)

P12 Condition (YFERT GREATER YMECH, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH A LOT)

P13 Condition (YMECH ABOUT EQUAL TO YFERT, YMECH MEDIUM)
    Action    (OLD (**), INCREASE BMECH, INCREASE BFERT)
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YMECH = Level of mechanization constraint
BMECH = Budget for mechanization
YFERT = *Level of the fertilizer constraint*
BFERT = Budget for fertilizer

Critical Review of the Oil, Agriculture
and Human Resources Modules for Saudi Arabia

Suggested Initial Structure for the
Decision Module for Saudi Arabia

Initial Assessment of Entire Model
by Ex-Flag Officers and Policy Planners

Dr. Warren R. Phillips
Mr. Robert C. Crain

July 1975
Project Research Paper No. 38

Contract No. RF280154

I. INTRODUCTION

This report is a critical review of, and suggested revisions for, the Saudi Arabian oil, agriculture, and human resources modules of the Project for Theoretical Politics. It also presents a recommendation for the initial structure of the governmental decision module that links the three substantive modules. Finally, it reports on the results of interviews with ex-flag officers and policy planners. In those interviews, the substantive modules were presented together with the proposed decision module so that the overall model could be critically assessed from the planner's point of view.

The review of the substantive modules was conducted in conjunction with area specialists and economists, and two types of criteria were employed in their assessments. The first type was concerned with the appropriateness of a module for its intended purpose. For example, since the substantive modules were all to function as models of processes to be controlled by the decision module, they had to be capable of accepting control inputs. Not only must these modules be dyanamic in that sense, but the control inputs identified in each module had to be governmental policies or actions, or variables that could be unambigously linked to one or the other. The second type of assessment criteria was concerned with a module's completeness and internal logical consistency. In essence, the search was for causal links that were inadequate, erroneous, omitted, or unnecessary. Toward this end, the assistance of area experts and economists was especially helpful.

Area specialists were also consulted during the formulation of an initial version of the decision module's structure. The many factors influencing Saudi decision-making and their complex and subtle interactions combined to make that formulation the most difficult task performed for this effort. The resulting structure should be regarded as a first cut whose continued development is essential.

The remainder of this report relates in detail the tasks mentioned above. Critical assessments of the oil, agriculture, and human resource modules, respectively, are presented in the next three chapters. Chapter V describes the suggested initial structure for the decision module, and Chapter VI presents the responses of ex-flag officers and policy planners to the model as a whole, together with resulting suggestions for further revision. Chapter VII speculates briefly on the implications of these efforts for the project's future research priorities.

II. CRITICAL ASSESSMENT OF THE OIL MODULE

The oil module, as presented in the Appendices to the Project for Theoretical Politics Research Paper #23, was considered reasonably acceptable on the criteria of appropriateness. It was specifically designed to be dynamic, with control inputs identified explicitly for the production subcomponent in Research Paper #15, and for the contractual (revenue-generating) component in Research Paper #23. Criticism elicited during the review process dealt with particular links in the model and each criticism will be discussed in turn below.

The first problem identified centered on the delay that occurs between a decision to increase production capacity through capital investment and the actual placement on-line of the new facilities. This delay, given in months, is the variable ADBR in the module's production subcomponent, and was set at three months in Research Paper #23. It was suggested that this value was unrealistically small and should be made larger. Just how much larger, however, depends on which of two assumptions is to be made. One possible assumption is that the increase in production capacity should result from the extension of pipelines and other gathering facilities to fields or pools that already contain drilled and capped wells and/or are near present production areas. For this type of increase in production capacity, a delay of six months may be considered reasonable. The second possible assumption is that any increase in capacity should result from drilling in, and then building gathering facilities for, fields or pools with only negligible development work already completed. Bringing such relatively undeveloped areas on-line would require a longer delay--perhaps two years. The former assumption is better for the project's purposes. The initial drilling and capping of wells in new fields or pools for future production is not an uncommon practice, and since daily production per well is so high in most Saudi oilfields, sizeable increases in capacity may be obtained by bringing on-line already initially developed areas or

drilling a few new wells in or very near an already developed area. The important restriction to bear in mind is that very large increases in capacity cannot be brought on-line quickly since gathering facilities already in operation would become saturated. Thus capacity-increase decisions fed into the module should be incremental and continued over a period of time to obtain moderate-to-large increases in capacity.

Another problem identified during the review concerns the omission of any requirements for capital investment to replace production capacity (equipment and wells) which becomes worn out or requires maintenance. This problem may be resolved by adjusting the production capacity (PC) variable at the end of each year. Capacity would decrease by a constant proportion equal to the reciprocal of the assumed average lifetime for that capacity, and could increase (back to its previous value) if capital were invested in replacement capacity. Thus the following equation would be invoked by the oil module at the end of each year:

$$PC_t = PC_{t-1}\left(1 - \frac{1}{LIFETIME}\right) + \frac{IREP}{COCR}$$

where PC = production capacity ($\frac{bbl}{da}$)

LIFETIME = length of time at the end of which capacity is worn out (yrs)

IREP = investment for replacement of capacity ($)

COCR - cost of capacity replacement ($\frac{\$ - da}{bbl}$)

Replacement of existing capacity is thus handled separately from expansion of capacity to permit production increases.

The treatment of additions to proved reserves should also be revised. Presently, such additions are based on monthly production rates, with PRM, the average ratio of net increases in reserves[1] to production levels, having

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[1] Net increases in reserves are equivalent to total new reserves discovered in a given time period minus cumulative production for that period.

been estimated from past performance. A better approach would estimate a fixed gross discovery rate from past performance. The resulting incremental growth in reserves could be overridden by the user if he so desired. The level of proved reserves could be arbitrarily increased by 50 percent for example, in order to simulate large new discoveries. Then incremental growth would resume. The phenomenon of consistently increasing reserves over time is unique to Saudi Arabia.[2] While incremental growth in Saudi reserves is a reasonable assumption for the present and at least short-term future, it should not be assumed over the very long term.

Some additional points made with respect to the module should be covered. First, the oil demand experienced by Middle Eastern producing countries is subject to seasonal fluctuation. This is not presently addressed in the module; on the other hand, most planning decisions by the producing-country governments are made on a fiscal-year basis and thus such fluctuations tend to balance out for decision purposes. Their omission is probably justified. Second, as Saudi Arabia moves toward a complete takeover of ARAMCO, the revenue-producing equations in the module may require additional revision since they explicitly reflect contractual terms. This problem could be overcome by aggregating the contractual terms into the imputation of a single net revenue per barrel figure for the government; but this would perhaps overly simplify the module's representation of the government's decision environment. On the other hand, operation of the production facilities as wholly Saudi-owned may yield a contractual basis which replaces the complex previous arrangements with a single price for oil and, in effect, obviates the problem.

The remaining problems with the oil sector lie not in the oil module itself but in the means of producing control inputs for it. More specifically, they lie in the specification of decision algorithms which produce the control information. These problems will thus be discussed in Chapter V.

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[2] Hitti and Abed (1974: 252). See also Warman (1973) for the difficulty in predicting future discoveries.

III. CRITIQUE OF THE AGRICULTURE MODULE

The agriculture module received more extensive criticism than the oil module. The module was dynamic and the control inputs required were budget and policy matters, so that the criteria of appropriateness were generally satisfied. In another sense, however, an important criterion of appropriateness was not satisfied. The agriculture module was constructed because it was thought that a drive toward agriculture self-sufficiency would be a major part of Saudi developmental policy. Area experts indicated, however, that references to such an effort in, for example, the most recent Saudi development plan are largely cosmetic. The funds allocated for agricultural development are nowhere near sufficient for the intense effort assumed as an underlying rationale for the module. Instead, the Saudis appear largely willing to import food to fill any deficit between domestic supply and demand. Hence the usage of the module within the overall model should be revised.

The traditional sector of the agriculture module can be largely ignored. People in this sector are engaged in subsistence agriculture. Crops grown by them are consumed locally and contribute little or nothing to the supply of food for the country's ubran regions. Individuals engaged in subsistence farming do represent a sizeable source of labor which, with education and training, could be diverted to a growing industrial sector. Rather than free up labor in the traditional sector by modernizing agriculture and greatly increasing individual productivity, however, the Saudis are considering importing surplus agricultural workers from Egypt.[3]

The modern sector of the agriculture module should also be treated differently than was originally envisioned. The Saudis are likely to make an extensive effort to develop a large, modern, irrigated agricultural

[3] See the summary of key features of the new five-year development plan for Saudi Arabia in Arab Press Service, May 26, 1975, p. 10.

sector only if the cost of importing food for urban areas exceeds some (relatively high) threshold or if insufficient quantities of food are available for purchase. There is, however, an ongoing government experimental farm program and some limited development of irrigation projects.[4] It was suggested, therefore, that the agriculture module's modern subcomponent be regarded as reflecting an experimental operation in which an ongoing effort is made to discover the optimum technology (usage combination of land, water, machinery, and fertilizer) for Saudi conditions. This could be easily accomplished by setting low limits on the amounts budgeted annually for fertilizer, machinery, and additional irrigation development and allowing a subcomponent of the decision module to attempt optimization under these constraints. The technological level achieved by this experimental effort at any time (as measured in terms of yield with specific mechanization and fertilization levels) could be used to produce estimates of how much it would cost at that time to gear up to produce a given quantity of wheat if a major development program were undertaken. If the excessive import cost threshold mentioned earlier were to be exceeded, then agricultural budget expenditures would be increased drastically in an effort to employ technology from the experimental farm on a much wider scale.

The import demand for food would be generated by replacing the present demand equation (C2 in Research Paper #32). Instead of the population index (POPI) and population growth (POPGR) variables representing the population as a whole, they would represent the level and growth rate of the urban population. The world price of wheat variable (WP) would be used to approximate the cost of importing the needed wheat provided that an adjustment for transportation costs is applied.

Given this overall shift in the usage of the agriculture module, several criticisms and suggested revisions of particular aspects of the modernized sector subcomponent should be addressed. The first criticism deals with

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[4] See, for example, Eigeland (1970: 22-29).

the delay involved after a budget allocation has been made for a new irrigation project and before that project is completed and performing at its design level. It was pointed out by economists that a shakedown period of one to two years is normally required after such a project is completed before it functions smoothly and reliably. Thus, the delay variable (IRRDELA) in the module should not be based solely on published estimates of construction time to completion. In addition, irrigation projects which involved dams may require different delay times than projects based upon ground-water wells.

Another suggestion was to establish a range of estimates for coefficients in the module's equations. Since many coefficients have been estimated on the basis of spotty or otherwise inadequate data, or their values simply assumed, estimates of high and low values should be provided in addition to the original value. The module may then be subjected to sensitivity testing the determine those coefficients whose values are most critical and which thus merit more careful estimation if possible.

The adjustment of the government's cost of subsidizing mechanization (for wheatland as a proportion of total irrigated land) in equation P4 should be removed. It is highly unlikely that a Saudi planner, when considering the cost of providing farm equipment for a given area, will be concerned with allocating portions of that cost to the production of different crops. In addition, wheat has been taken as an indicator of the entire agricultural sector, and all fertilizer purchased by the government is assumed to be applied to wheat; thus allocating all machinery cost to wheat is consistent with other assumptions.

The geographic distribution of machinery is another consideration which was not addressed directly in the module. There are essentially two strategies that a Saudi decision-maker could employ when providing farm machinery. The first is to distribute the equipment uniformly over the land to be mechanized. The second is to determine the level of mechanization required to produce high yields and then concentrate the machinery on

a portion of the land which could be mechanized in an attempt to reach a target yield figure. The implications of these strategies for total production may be quite different. Economists suggested that the probable tendency of a typical planner would be to concentrate the machinery in smaller areas, and that the possibility that such a policy might constitute suboptimization should be considered.

The effects of geographical distribution are partly embedded in the line representing yield constraint as a function of mechanization level. If there is a "critical mass" effect with machinery so that minimum amounts are necessary for a given land area before much of an impact on yield occurs, the line would have a step-level change at some point instead of being continuous as is presently the case. A straight line would imply that, ceteris paribus, uniform distribution of machinery would be the optimal policy while the step-level increase would imply the opposite unless sufficient machinery was involved to bring the entire area above the threshold.

Roughly analogous remarks could be made about fertilizer distribution except that the shape of a fertilizer yield function is well known and the smooth curve presents a rather straightforward optimization problem to the planner. A family of curves having the same shape should, however, be used to determine the effects of a range of assumptions.

Economists also suggested that it would be desirable to combine the effects of fertilizer, water, and mechanization on yield into a single function since their effects are interactive.[5] It was recognized, however, that this might be extremely difficult and perhaps impossible depending on the amount of information available. At a minimum, a family of curves should be tried for each separate function, where each curve would represent the best estimate of yield response to a particular input given explicit assumptions of the values of the other inputs.

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[5] Each of the present yield curves represents, in effect, a partial derivative of yield with respect to some given input.

A by-product of the discussion of yield curves was the identification of an additional assumption implicit in the curves of Research Report #32. The assumption is that water and fertilizer are always applied at the appropriate times. This may be an appropriate assumption for an experimental farm, but it is by no means trivial.

The equation (C2) used to calculate demand for wheat should be modified to remove the assumption of a constant income elasticity. Economists pointed out that demand may only increase with income up to a point; beyond that point it may remain constant or decrease. The assumption of constant elasticity is appropriate only if it is also assumed that per capita income will not rise above the point at which demand levels off or decreases. An indication of the acceptability of the second assumption might, it was suggested, be gained by examining per capita demand for wheat in other countries at various levels of development. If the second assumption is found to be unwarranted, the income elasticity of demand for wheat should be made a function of private consumption expenditures.

Fault was also found with measures of income and productivity employed in the agriculture module. Economists pointed out that income for the agricultural sector is usually measured on a per family rather than a per person basis (especially where agriculture is largely traditional). Given that the agriculture module's traditional sector will now be ignored, however, there seems little reason to retain a measure of agricultural family income. Similarly, the labor productivity measure should be revised to provide information only on those involved in modernized agriculture.

Finally, it was suggested that purely definitional equations (such as that for labor productivity) be removed from the model per se, as they make it somewhat cluttered. Since such equations define monitor variables used as performance indicators, they may be relegated to the decision module's observation interface.

IV. CRITIQUE OF THE HUMAN RESOURCES MODULE

On first reading, the human resources module appears to be the best of the three. Unfortunately, when the criteria of appropriateness are applied against the module, it is seen to have serious faults. The main problem is that the module is not dynamic. Transition constants that determine implicitly the population growth rate and explicitly the flow from category to category within the module are static. There exists, for example, no way for educational expenditures to influence the number of students or the dropout rate. This state of affairs was acknowledged in part IV of Research Paper #31, as was the solution: a set of algorithms relating transition constants to government expenditures or other policies. No work has been done along these lines, however, and thus a most undesirable situation exists for the decision module. Perhaps the most critical sector in terms of its impact on potential development is not susceptible to control. Essentially there are only two remedies available: provide the algorithms or redo the module.

In addition to the lack of control input to the human resources module, there exist several problems of a more substantive nature which were pointed out by area experts. To begin with, the module does not distinguish between Saudi Arabia's indigenous labor force and the relatively large amount of skilled foreign labor employed there. Not only is skilled foreign labor presently used in large quantities, but the current Saudi development plan suggests that even more will be imported.[6]

Another problem with the module is that it does not distinguish between students enrolled in religious schools and universities and those enrolled in modern conventional ones. The graduates of the different types of schools differ in their capabilities to become effective managers, technicians,

[6] See Arab Press Service, May 26, 1975, p.10.

and bureaucrats quickly. In addition, estimates of population (and, as a result, those for manpower) are probably too high. The population estimate of 8,200,000 for 1972 in the module, for example, should be adjusted downward in light of more recent estimates of 1972 Saudi population of 7,200,000 from one source[7] and 4.1 million from another.[8] For planning purposes it would seem more appropriate to employ the lower estimate because of its implications as a bottleneck, but a range of estimates should be tested for their implications.

Estimated percentages of the work force falling into various categories are also somewhat erroneous. In particular, the percentage (74.0) for self-employed agricultural workers should be lowered (to about 45 percent), and that for petroleum wage earners (1.0) raised (to about 2.5). Taken as a group, the self-employed non-agricultural, non-industrial wage earner, and non-petroleum industrial wage earner categories should be increased from 10 percent to about 30 percent. Area experts emphasized that, in general, there exists a relatively wide range of estimates in various published sources of both the Saudi population and its breakdown by manpower and other human resource categories. Thus it becomes important to look for convergence when selecting estimates from the literature or to employ a range of estimates if no convergence exists.

The preceding criticisms have focused largely on the data used in estimating model parameters. The module also assumes the values of some parameters in order to estimate others. Area experts were specifically requested to assess the values assumed in light of their knowledge. The assumption of .75 for X_{22},[9] which implies that 25 percent of the pupils in primary grades either move into the intermediate grades or drop out, was considered reasonable. Similarly, the assumed value of .5 for X_{33} (the proportion of intermediate school pupils returning each year) was

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7 Hitti and Abed (1974:247)

8 Knauerhase (1974:127)

9 The subscripts of X represent its position in the transition matrix shown on p. 19 of Research Paper #31.

not criticized. The value of .075 estimated for X_{32}, however, was regarded as probably a bit small; more than 7.5 percent of the primary-level pupils probably go on to the intermediate level. Since X_{32} was estimated, X_{33} would have to be reduced slightly in order to raise X_{32} somewhat. Alternatively, one might assume that the error results from inaccuracies in the data and retain the present value of X_{32}. Given the importance of substantively reasonable assumptions and the difficulty of obtaining data on the Saudi educational system, the better choice for the present situation would probably be reestimating X_{32}.

Other transition constants were criticized. Perhaps the best procedure of reporting the criticism is to do so by manpower category into which people are flowing. In terms of the transition matrix in Research Paper #31, this means that the constants will be reported on a row at a time. In row 6, X_{613} is assumed to be zero, and thus no self-employed, non-agricultural workers (for example, shopkeepers and owners of taxis or auto repair shops) attend school. This is incorrect. Most of those attending adult basic education classes are high-achieving, self-motivated individuals, and are likely to come from this self-employed category. Similarly, an examination of the constants in row 7 suggests that each year 15 percent of those enrolled in technical/adult education enter a university. University students come almost entirely from secondary schools, and therefore X_{76} should be near zero.

The source of petroleum wage-earners is indicated in row 8 to be the unstructured pool. In reality, nearly all of those hired by the oil industry have at least a primary education, and at least a few are university graduates.[10] Thus X_{82}, X_{84}, and X_{87} should all be greater than zero. Non-petroleum (industrial) wage earners are shown in row 9 to come entirely from the unstructured pool and intermediate education. Some industrial workers, however, come from technical schools, and one would assume that at least some industrial managers are college graduates. Thus X_{96} and X_{97} should be greater than zero. Some uncertainty exists

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[10] Letter from W.P. O'Grady of ARAMCO.

with respect to X_{102}. It has been suggested (Knauerhase, 1974:128) that some Saudi government jobs are filled by dropouts from primary school. Since one would expect only a limited number of jobs for young boys, this would imply that a reasonable number of students in the primary grades start at a late age and then quit as soon as they are able to qualify for government jobs. If such students are included in the primary (elementary) education category, then X_{102} should be greater than zero. If, on the other hand, such students are included in the adult/technical education category, the assumption that X_{102} is equal to zero is quite reasonable. Additional knowledge of the structure of the Saudi educational system is necessary to resolve this problem. In addition, the graduates of teacher training schools are employed primarily by the government. Instead, such individuals are shown entering several different categories. Thus X_{105} (the proportion of teacher training pupils entering government service each year) is too low and some other transition constants in column 5 are too high.

Area experts pointed out that the Saudi army draws most of its officers from secondary school graduates and most of its enlisted men from illiterates, with almost none of its officers having university degrees. Accordingly, the figures of .067 for X_{117} (univeriaty students), 1.0 for X_{116} (technical/adult school students), and .133 for X_{115} (teacher trainees) should be zero or near zero.

The non-industrial wage earner category has a value of .133 for X_{125} (the transition constant from the teacher training category). As pointed out earlier, teachers work primarily for the government, and the assumption that 27 percent of those leaving each year (or 13.3 percent of the total number enrolled) enter this category is probably too high.

The final substantive criticism made by the area experts is that the module permits no flow from the agricultural self-employed category to non-agricultural labor categories such as oil, military, and non-industrial wage earners. A major thrust of the Saudi development effort is to

transfer manpower out of subsistence agriculture and into more productive employment by bringing in foreign agricultural laborers if necessary. The assumption that X_{114} through X_{1314} are all zero is thus not justified.

V. SUGGESTED INITIAL STRUCTURE FOR THE DECISION MODULE

Introduction

Development of a plausible initial structure for the Saudi decision module was a difficult task. The Saudi government has a very small bureaucracy relative to its income so that the decision-making process is highly personalist. Very little exists in the way of a published literature to give insight on the process, and data that would permit us to infer something about the process are either nonexistent or often not completely reliable. Moreover, recent large increases in Saudi Arabia's oil revenue, together with the country's emergence as a leader among Arab nations and the increased dependence of industrialized nations on petroleum from the Middle East, have introduced a large element of uncertainty into whatever inferences we might be able to draw from past periods.

Thus the structure presented in this section should be regarded as only a first cut. It will, however, provide a focus for the further analysis of Saudi decision-making and development of a more sophisticated model. Moreover, such a specification was needed in order to link the three substantive modules into a single entity for presentation to policy planners. In the discussion that follows, the suggested initial decision structure will be explicated and needs for further development identified.

Preliminary Considerations

Before attempting to specify the structure of the decision module, it was necessary to decide what kinds of policy outputs are most important in Saudi Arabia. In the developed countries, many kinds of governmental policies may be considered important to the conduct of domestic and foreign affairs. For example, tax policies, regulatory and tariff policies, environmental policies, defense spending, and so on may all have a

considerable influence on large parts of a nation's population and economic affairs. In Saudi Arabia, however, the situation is much simpler. Although the government is involved to some extent with all the examples just mentioned, its primary policy focus is the use of oil revenues to develop a diversified economy. It is not extensively involved with relatively subtle tinkering with a large and economical powerful private sector (excluding oil) because none at present exists.

Thus the focus of the decision module became budgetary allocations and how (and why) they are produced. This in turn influenced the module's assumed time frame. Each iteration of the module is equivalent to one Saudi fiscal year. These fiscal years are based on the Moslem calendar, however, and the correspondence between them and Gregorian calendar years is shown below:

Moslem Fiscal Year	Gregorian Calendar Date at End of Moslem Fiscal Year[a]
1382/83	November 16, 1963
1383/84	November 4, 1964
1384/85	October 24, 1965
1384/86	October 14, 1966
1386/87	October 3, 1967
1387/88	September 22, 1968
1388/89	September 11, 1969
1389/90	September 1, 1970
1390/91	August 21, 1971
1391/92	August 9, 1972
1392/93	July 30, 1973
1393/94	July 20, 1974

Since the Gregorian date on which the Saudi fiscal year begins changes each (Gregorian) year, the decision module must keep track of this. For the human resources module, the changing start date is unimportant. The

[a] Source: Hitti and Abed (1974: 279).

slightly longer Gregorian years have been used in the estimation of transition constants, but this is assumed to be negligible for present purposes. For the agriculture model, the changing start date is also probably irrelevant at present because relatively little central agricultural planning and budgeting have been done in the past or are being done presently. The oil module operates on a monthly basis and exogenous disturbances that affect it (for example, a reduction in demand) may be introduced during any month. The effects of such a disturbance may well be quite different depending on whether it occurs at the beginning, the middle, or toward the end of a fiscal year. Thus, if the decision module is assumed to iterate once per Saudi fiscal year, the month in which the oil module starts must correspond--at least roughly--with the start of the fiscal year involved. A simple way of approximating the desired correspondence would be to change the oil module's start month to the next earlier month every fourth year.

Given that the decision module was to be concerned with budget decisions and was to operate on the basis of the Saudi fiscal year, work could progress on the module's basic structure. The result is shown in the flowchart in Figure 1. Each step in the flow will be discussed briefly below, along with its underlying rationale.

<u>Module Description</u>

In the discussion that follows it is assumed that a program exists that schedules the execution of the actual decision and substantive module programs, and communicates with the user of the simulation when necessary.

As indicated in the flowchart, the user is first asked for the date at which the simulation is assumed to begin. Because initial values must be specified for a host of variables for whatever start date is assumed, it is suggested that a reasonable default start date (or set of dates) be chosen and initial values for all appropriate variables for that date (or dates) be read into the program from a permanent file.

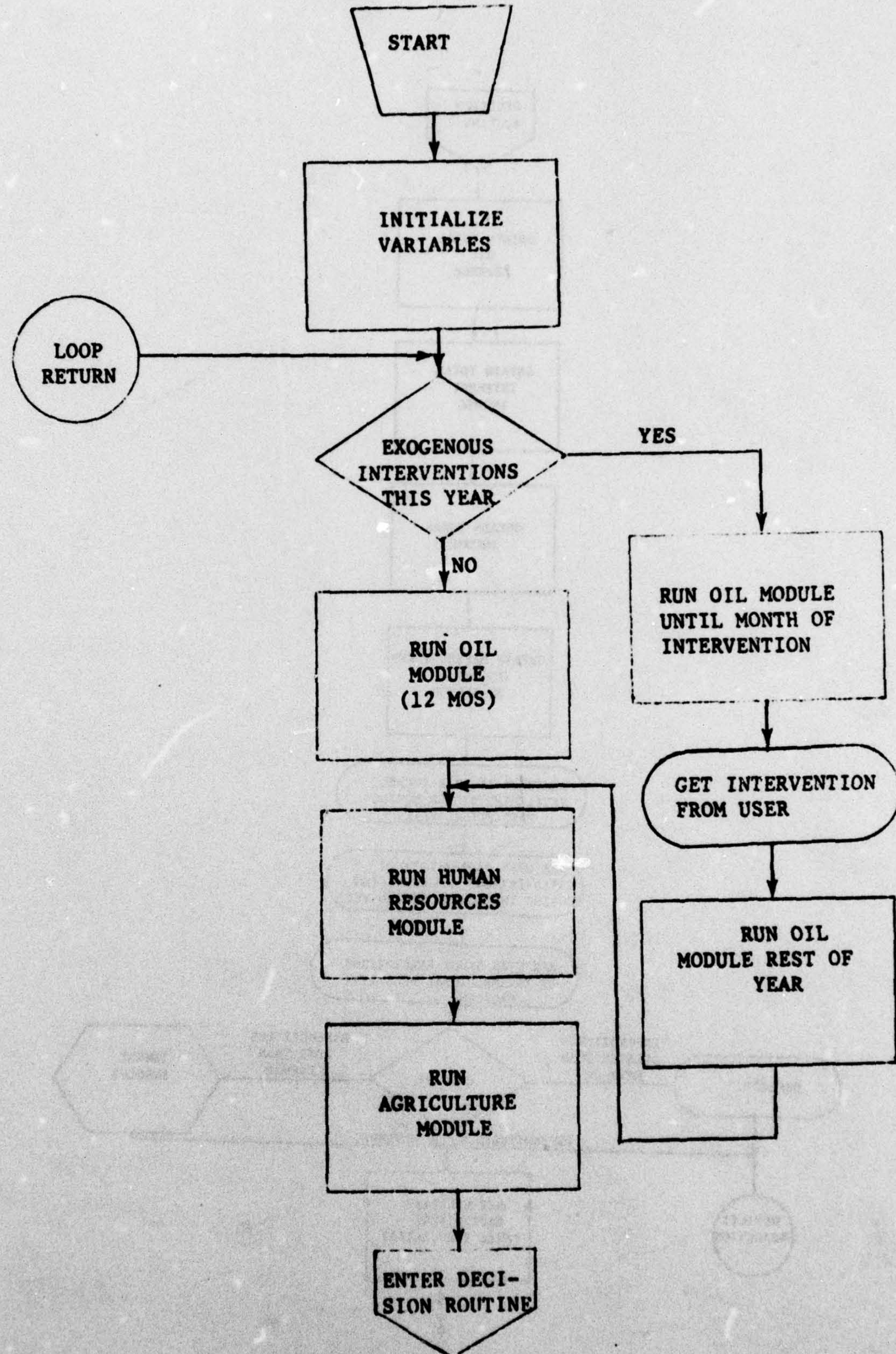
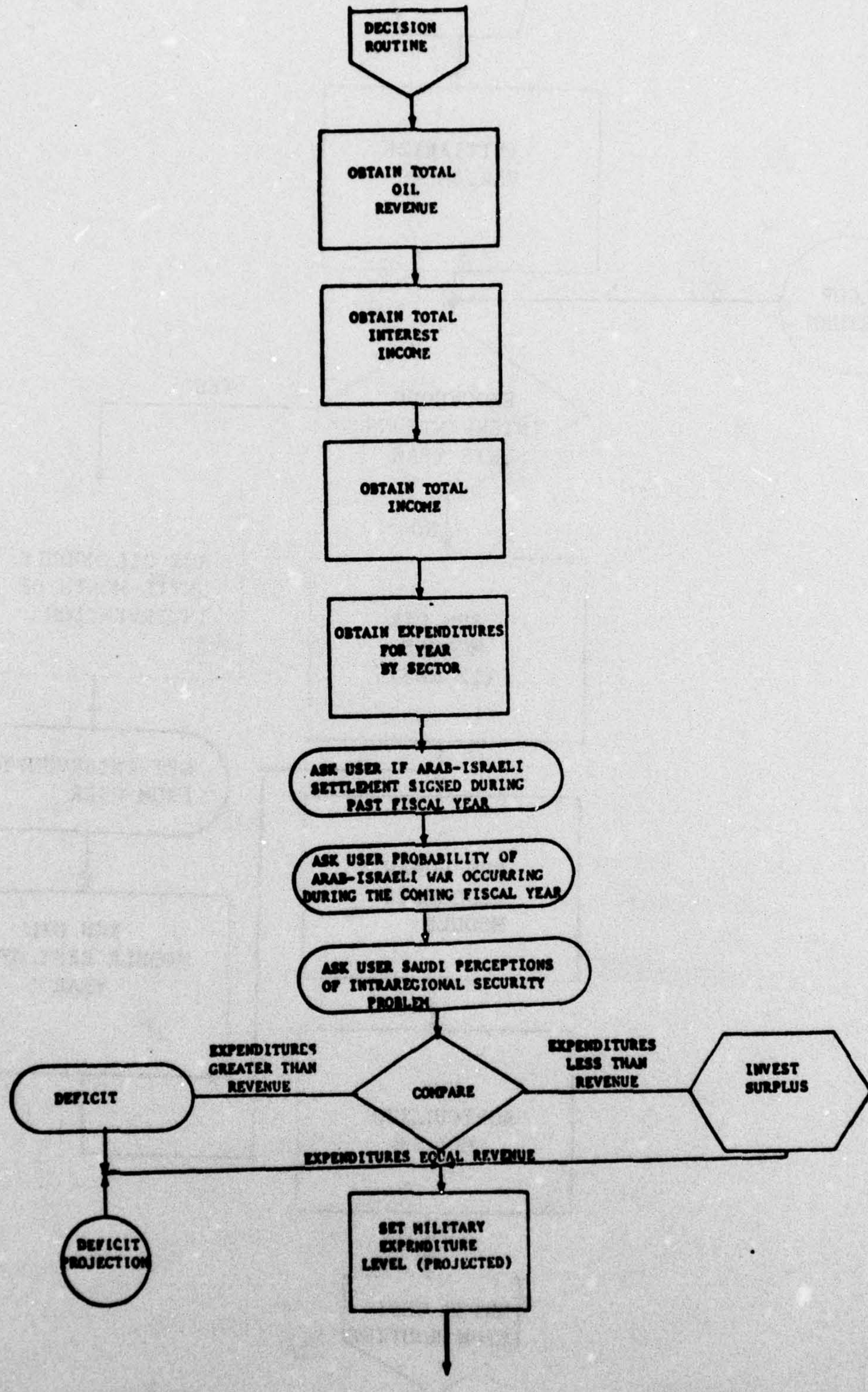
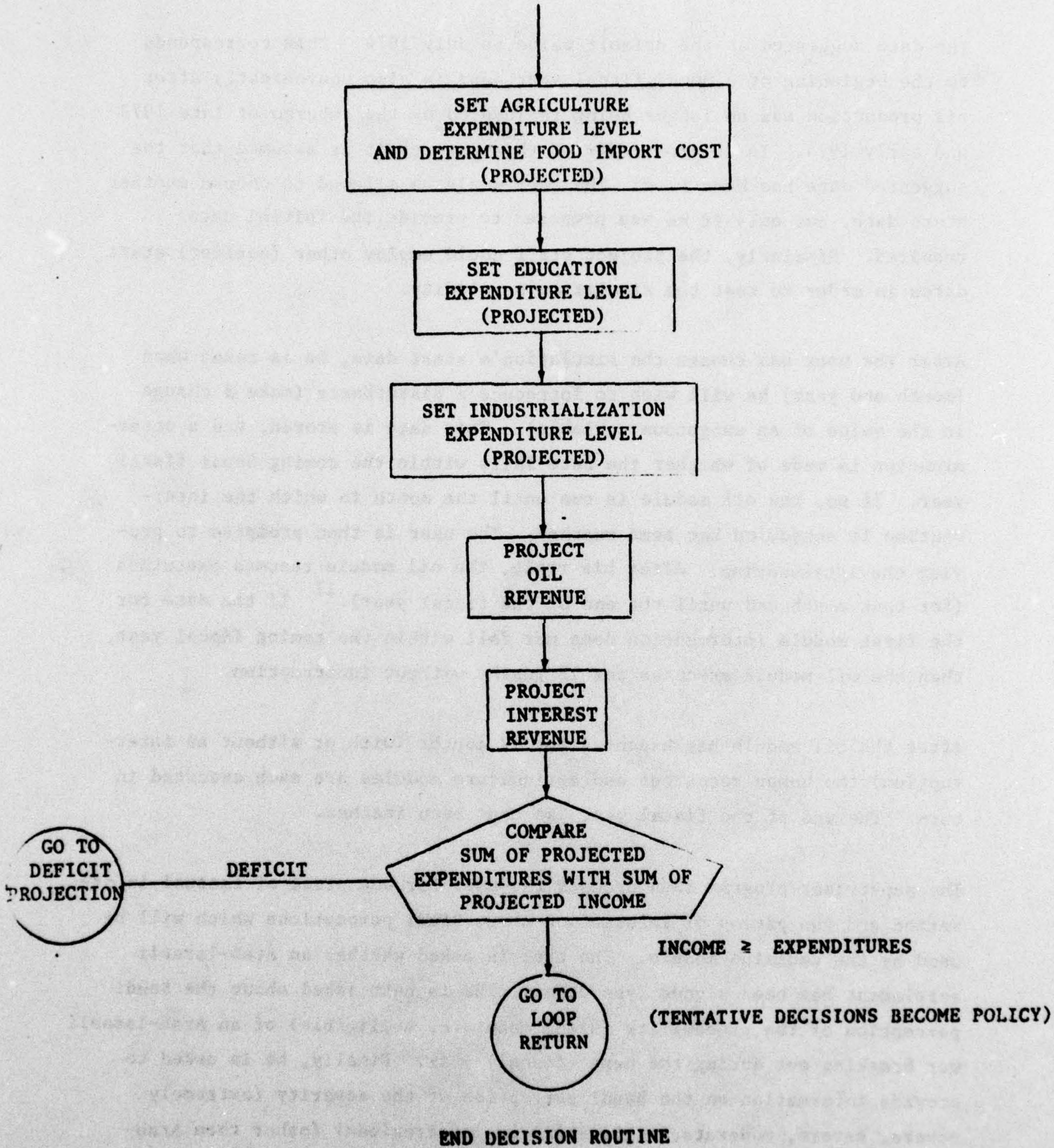


Figure 1. Flowchart of Decision Module


DECISION ROUTINE
OBTAIN TOTAL OIL REVENUE
OBTAIN TOTAL INTEREST INCOME
OBTAIN TOTAL INCOME
OBTAIN EXPENDITURES FOR YEAR BY SECTOR
ASK USER IF ARAB-ISRAELI SETTLEMENT SIGNED DURING PAST FISCAL YEAR
ASK USER PROBABILITY OF ARAB-ISRAELI WAR OCCURRING DURING THE COMING FISCAL YEAR
ASK USER SAUDI PERCEPTIONS OF INTRAREGIONAL SECURITY PROBLEM
EXPENDITURES GREATER THAN REVENUE
EXPENDITURES LESS THAN REVENUE
DEFICIT
COMPARE
INVEST SURPLUS
EXPENDITURES EQUAL REVENUE
DEFICIT PROJECTION
SET MILITARY EXPENDITURE LEVEL (PROJECTED)


SET AGRICULTURE
EXPENDITURE LEVEL
AND DETERMINE FOOD IMPORT COST
(PROJECTED)
SET EDUCATION
EXPENDITURE LEVEL
(PROJECTED)
SET INDUSTRIALIZATION
EXPENDITURE LEVEL
(PROJECTED)
PROJECT
OIL
REVENUE
PROJECT
INTEREST
REVENUE
COMPARE
SUM OF PROJECTED
EXPENDITURES WITH SUM OF
PROJECTED INCOME
DEFICIT
GO TO
DEFICIT
PROJECTION
INCOME ≥ EXPENDITURES
GO TO
LOOP
RETURN
(TENTATIVE DECISIONS BECOME POLICY)
END DECISION ROUTINE

The date suggested as the default value is July 1974. This corresponds to the beginning of a Saudi fiscal year, and is also conveniently after oil production was no longer being influenced by the embargo of late 1973 and early 1974. In the remainder of this chapter it is assumed that the suggested date has been used. The user would be allowed to choose another start date, but only if he was prepared to provide the initial data required. Similarly, the project staff could employ other (earlier) start dates in order to test the simulation's validity.

After the user has chosen the simulation's start date, he is asked when (month and year) he will wish to introduce a disturbance (make a change in the value of an exogenous variable). This date is stored, and a determination is made of whether the date falls within the coming Saudi fiscal year. If so, the oil module is run until the month in which the intervention is scheduled has been reached. The user is then prompted to provide the intervention. After his reply, the oil module resumes execution (for that month and until the end of the fiscal year).[11] If the date for the first module intervention does not fall within the coming fiscal year, then the oil module executes for 12 months without interruption.

After the oil module has executed for 12 months (with or without an interruption) the human resources and agriculture modules are each executed in turn. The end of the fiscal year has thus been reached.

The supervisor program then prompts the user for one piece of factual information and two pieces of information about Saudi perceptions which will be used by the decision module. The user is asked whether an Arab-Israeli settlement has been signed (yes or no). He is next asked about the Saudi perception of the probability (high, moderate, negligible) of an Arab-Israeli war breaking out during the next (fiscal) year. Finally, he is asked to provide information on the Saudi perception of the severity (extremely severe, severe, moderate, negligible) or intraregional (other than Arab-Israeli) security problems. Then the decision module begins execution.

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[11] It has been assumed, for the sake of simplicity, that only one intervention per year is desired. More than one may easily be permitted.

It will evaluate the various sectors' performance for the year just ended and decide on spending levels for the fiscal year to come.

In reality the Saudi planning and decision process is an ongoing one; to have the decision module function only at the end of a fiscal year is an obvious oversimplification. Yet to attempt to have the module produce control information for the oil module on a monthly basis or work incrementally on the coming year's budget is probably overly ambitious until more is known about Saudi decision-making. Thus, for present purposes, "time will stop" while the decision module evaluates and plans.

The evaluation of the fiscal year just ended is a relatively primitive one. First, information on revenue from oil production for the year is obtained and added to the interest on short- and long-term investments to obtain total revenue.[12] Then government expenditures for all sectors are summed. Total expenditures are compared with total revenue and the result is either a revenue surplus, a revenue deficit, or an approximate balance between revenue and expenditures. If a revenue surplus has occurred, the government must decide what to do with its excess revenue. The choice is between two alternatives: long-term investments (real property or equities) or short-term investments and bank deposits. It is assumed that Saudi Arabia will not put much into the long-term investment category unless an Arab-Israeli settlement has occurred. Given such a settlement, the proportion of surplus funds invested in this category would probably be small initially and rise over time to some ceiling proportion that represented the Saudi's desired liquidity goal. (See Figure 2). The remaining funds would be placed into the short-term category. If a settlement has not occurred, it is assumed that all surplus funds would go into the short-term category. If a settlement has occurred, but for some reason appears likely to break down in the coming year, the surplus would all be placed into the short-term category. An approximate

[12] Non-oil domestic revenue is very small and is being ignored for present purposes.

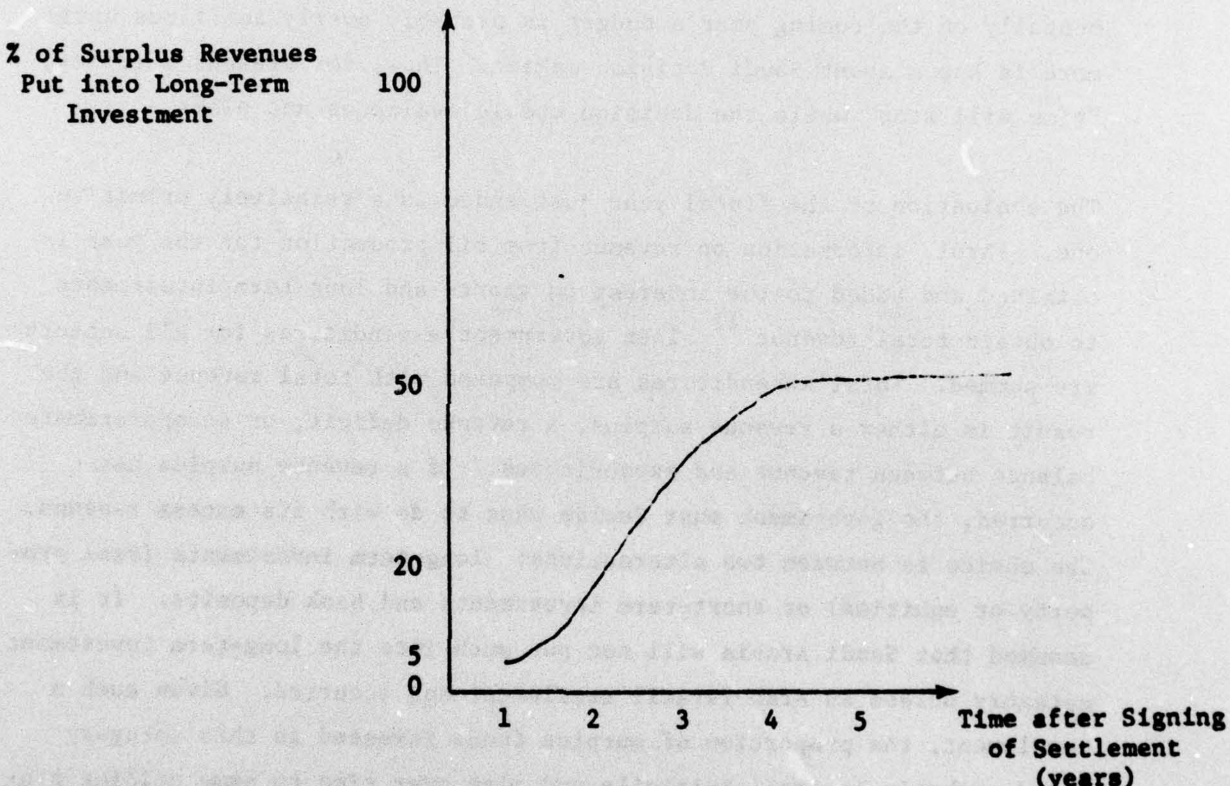

Figure 2. Level of Long-Term Investment after Arab-Israeli Settlement

balance between revenue and expenditures would result in the small surplus being invested (or banked) on a short-term basis or the small deficit being covered by a withdrawal from short-term money of the amount necessary to produce a balance. The case of other than a very small deficit is difficult to deal with and is discussed in a separate section later in this chapter. For present purposes it is assumed that if a moderate or large deficit occurs, a branch is made to a deficit subroutine the structure of which is as yet unspecified and control then returns to the beginning of the routine where projections are made of expenditures for the coming fiscal year.

Tentative expenditures for the coming fiscal year are next established by category. The first expenditure level to be set is that for military expenditures. This is assumed to be made up primarily of money spent for imports of military equipment. The algorithm used for setting a trial expenditure level is as follows:

$$M_t = M_{t-1} * (\alpha_1 + \alpha_2 + \alpha_3)$$

where

M = level of military expenditures and α_{1}, + α_{2}. + α_{3}, are coefficients whose values are set according to the following scheme:

$$\alpha_1 = \begin{cases} +.10 & \text{if high revenue surplus previous year} \\ +.05 & \text{if low revenue surplus previous year} \\ .00 & \text{if revenue approximately equals expenditures previous year} \\ -.05 & \text{if low revenue deficit previous year} \\ -.10 & \text{if high revenue deficit previous year} \end{cases}$$

$$\alpha_2 = \begin{cases} +.20 & \text{if extremely severe intraregional}^{13} \text{ security problems} \\ +.10 & \text{if severe intraregional security problems} \\ +.05 & \text{if moderate intraregional security problems} \\ +.00 & \text{if negligible intraregional security problems} \end{cases}$$

$$\alpha_3 = \begin{cases} +.10 & \text{if high probability of Arab-Israeli conflict in next year} \\ +.05 & \text{if moderate probability of Arab-Israeli conflict in next year} \end{cases}$$

[13] Excluding Arab-Israeli Conflict

$$\left\{ \begin{array}{l} +.00 \text{ if negligible probability of Arab-Israeli} \\ \quad \text{conflict in next year.} \end{array} \right.$$

The second expenditure level to be set is that for education. The algorithm by which this is done is as yet undetermined. A brief summary of the effort made and problems encountered in the attempt to specify such an algorithm may be found in a separate section later in this chapter.

The expenditure for agriculture is set next. This is equal to the amount required to import food (as measured by wheat) for the urban areas[14] plus a small amount (assumed to increase incrementally) for water, fertilizer and machinery to be used in the government's experimental farm program, unless the threshold of excessive import cost has been passed (probably for more than a single year). In the latter case the amounts spent to modernize and develop domestic agriculture would increase drastically. Area experts suggested that the threshold amount is probably very large (perhaps 10-20 percent of the country's revenue), and that it is unlikely to be reached.[15]

The final expenditure to be determined is that for industrial development. It is unclear just what the algorithm involved should be. Information on the new Saudi development plan[16] indicates that approximately $13 billion is to be invested over a 5-year period in building heavy industry, but area specialists suggest that it is unlikely that all of this sum will actually be spent. Since little industry (other than oil) presently exists in Saudi Arabia, it is also difficult to infer what the Saudis might use as performance indicators to assess and adjust an ongoing attempt to build an industrial sector. What is clear is that industrialization is a high priority

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[14] The food demand for urban areas would be reduced by the amount of food produced by the modernized agricultural component. This amount will be small unless the threshold has been passed long enough to produce vastly increased domestic agricultural expenditures and for those expenditures to produce results.

[15] In addition, alternatives other than domestic investment exist. For example, it has been suggested that an investment in the Sudan, a country with great agricultural potential but with limited capital, might yield a much greater rate of return than development of domestic agriculture.

[16] Arab Press Service, May 26, 1975, p.10

for the Saudis, that large developmental expenditures will be made in pursuit of that goal, and that thus such expenditures should be taken into account in the decision module.

The projected expenditures in the categories mentioned above are summed and the total is compared with projected revenue for the coming year Revenue projections are made on the following basis. First, interest on investments is computed at user-provided assumed rates of return. To this is added projected oil revenue, which is estimated on the basis of a simple extrapolation from last year's revenues after a check is made of the acceptability of the present production rate. If the present rate is unacceptable, an adjustment is made. The scheme for evaluating production rate and making adjustments is described in a later section of this chapter. If the rate is acceptable, then the extrapolated revenue is added to the projected interest income and the total projected revenue compared with the total projected expenditures. The revenue and expenditure projections are considered satisfactory if an approximate balance or a revenue the supervisor program, which then runs the oil, agriculture and human resources modules for the next year, stopping during the year if an intervention is desired by the user. If a deficit is forecast, then the decision module returns to the point at which military expenditures are projected and cycles through again as if a deficit had occurred during the fiscal year just ended. Presumably, after at most a few iterations, either an approximate balance between projected revenue and expenditures or a projected revenue surplus will be reached and control will be transferred to the supervisor program.[17]

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[17] This is not a trivial matter. If a very large deficit were forecast it would probably be unrealistic to assume that it would be overcome by many successive incremental budget cuts. In such circumstances Saudi decision-makers would probably make bold cuts in one category or another depending on their priorities. As mentioned earlier, inferring what these actions might be is difficult. See the section on deficits in this chapter.

Consequences of Revenue Deficits

As indicated earlier, attempting to specify even very simple Saudi decision rules for coping with a deficit is extremely difficult. At the heart of the difficulty is the need to specify where spending cuts would be made if necessary. It was suggested by area specialists that how the Saudis would respond to a deficit depends on whether they perceive it is a temporary phenomenon or as a long-term trend. Their extraordinary large reserves would permit them to deal relatively easily with any small deficit, and to cope with a large deficit on a one-time basis without insurmountable problems. But even small deficits would probably be unacceptable over time; large ones certanly would.

As described in this chapter, the initial structure of the decision module assumes that the response to a small deficit would be at least a cut in the next year's projected military spending. Presumably, projected spending in certain other sectors would be adjusted downward, and this should be taken into account in specifying budgetary decision algorithms for those sectors. The problem is to identify the sectors to be cut. One means of attacking this problem would be to examine Saudi budgets from 1958 to 1974. During the first decade or so of this period the Saudis had considerably less oil revenue and were engaged in a program to repay sizeable government debts from deficits incurred before Faisal's influence was felt. Then, in more recent years, oil revenue increased steadily. An examination of changes in amounts budgeted in the various sectors as revenue increased, and earlier when debt repayment constrained spending, could shed some light on the ordering of Saudi goals.

Problems Involved with Specification of an Algorithm for Determining Educational Spending

The initial approach to specifying an algorithm for setting expenditure level in the educational sector was to use the human resources module to provide information on the total number of students at all educational

levels and then multiply this number by an assumed figure for cost per student. The cost per pupil was assumed to rise incrementally over time until it reached a ceiling value. An estimate of the ceiling value was to be made by examining Kuwait expenditures per pupil. Kuwait would serve as an example of a "mature" oil-rich country in which social welfare expenditures had stabilized at a plateau. In the Saudi budget for the fiscal year beginning July 1974, however, the education allocation was raised 68 percent over that of the previous year, doubtless in part because of the large increase in government oil revenues following the late 1973 price rises. That 68 percent increase, however, put the Saudi per pupil rate at about twice that of Kuwait. Thus the motion of Kuwait as a "mature model" for education seemed to be of rather limited utility. Moreover, no satisfactory explanation for the 68 percent increase could be found, and Saudi expenditures had already been at a very high level. The conclusion drawn was that educational expenditures and their justification would require intensive investigation before an algorithm could be formulated with anv confidence

<u>Saudi Evaluation of Their Oil Production Rate</u>

In the decision module, the Saudis are assumed to determine whether the past year's production rate (in barrels per day) is appropriate for use during the coming fiscal year. Its suitability is influenced by several factors. First, the Saudis can sell no more oil than is demanded by their customers; this exogenous variable is thus assumed to act as an upper bound for acceptable production values. Second, in times when demand is less than capacity for OPEC nations taken as a group, each member's production level is set approximately under an informal allocation scheme. Area specialists pointed out that the scheme is quite effective in spite of its informal nature, and thus Saudi Arabia should not be considered to have wide flexibility in setting its production rate subject only to demand constraints.[18] Finally, the production rate is subject to

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[18] For example, sizeable Saudi production cuts below their allocation level in a period of unchanging demand would provide pressure for either increased production by other OPEC members (strongly opposed by some members) or increased price (opposed by Saudi Arabia).

constraints concerning reservoir damage and reserve life. Extremely high production rates over short periods of time would violate the former, and at some point even moderate rates would violate the second.

Attempts were made to include these factors in the design for the decision module. It was assumed that the user will provide information on demand. This information would be embodied in a variable which could express demand either directly in barrels per day or in the form of an index relative to demand at the start time chosen.[19] In either case, however, such demand information is further assumed to be adjusted by the user for the effects of OPEC production allocation schemes. Thus this variable forms an upper constraint on production level. If production is at this level and the user intervenes during a fiscal year and lowers this value, then the production rate is lowered immediately to the new value for the balance of the year. Similarly, a rise in demand is responded to immediately if it does not require production in excess of current capacity.

Since downward adjustment of production in response to decreases in demand is automatic, the first check made by the decision module during evaluation of production rates is to make certain that reservoirs are not being damaged or reserves depleted too soon. It has been assumed that these two criteria interact with a third, namely, whether the country's absorptive capacity is surpassed at present levels of oil revenue. The value of this variable may be either given by the analyst (as is presently assumed to be the case) or built into the module. Tables 1 and 2 show how yes/no values for variables representing each of the three criteria are assumed to combine to produce Saudi decisions on production level. Reservoir damage is assumed to occur if the productive level is high enough to deplete reserves in 10 years. It is also assumed that Saudis would undertake strong conservation measures if the ratio of proved reserves to current production is less than 15 years.

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[19] An actual value for production rate would still be required for the start date.

TABLE 1

VARIABLES	SITUATIONS							
	1	2	3	4	5	6	7	8
Absorptive Capacity Surpassed	Y	Y	Y	N	N	N	N	Y
Reservoir Damage Occurring	Y	Y	N	N	Y	Y	N	N
Reserve Life Running Out	Y	N	N	N	N	Y	Y	Y

Y = Yes

N = No

TABLE 2

SITUATION	RESPONSES
1.	Cut production so that reserves/production = 15. The resulting production value will decline each year.
2.	Cut production to just below reservoir damage point.
3.	Maintain production at present level.
4.	Maintain production at present level.
5.	Cut production to just below reservoir damage point.
6.	Cut production so that reserves/production = 15. The resulting production value will decline each year.
7.	Cut production so that reserves/production = 15. The resulting production value will decline each year.
8.	Cut production so that reserves/production = 15. The resulting production value will decline each year.

This figure has been used as the criterion for whether reserve life is running out.[20]

After the module has ensured that the production level satisfies the "normal situation" constraints just mentioned, it checks whether an Arab-Israeli war is occurring. If so, it ascertains whether its customers are supporting Israel.[21] An embargo (expressed as a cut in production) is imposed on Saudi customers if they support Israel.

Given the production level established at this point, the decision module goes on to project revenue for the coming fiscal year on the basis of that level and the price of oil. Area specialists indicated that an OPEC country has only a very limited ability to alter the price of its oil around the price agreed upon at OPEC meetings. Such marginal price adjustments have been ignored in the present model structure. The price of oil is assumed to be an "OPEC" price,[22] and this price is to be supplied exogenously by the user.[23] Once the revenue for the coming fiscal year has been projected, the module goes on to project interest income and then compare total projected revenue with total projected expenditures, as described earlier in this chapter.

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[20] Reservoir damage can occur as the result of production at very high levels for even a relatively short period of time. Since the consequences of reservoir damange (a decline in the amount of oil than can ultimately be extracted from a reservoir) are so severe, it is assumed that production at such high rates would not be considered by the Saudis under most conditions. Moreover, if they did produce at such rates they would do so for only a short period of time (one year assumed at present). Thus if the module finds that reservoir damage is occurring, it looks at the production rate for the previous year in assessing the anticipated reserve life. Otherwise reserve life is evaluated on the basis of the present year's production rate.

[21] The occurrence of an Arab-Israeli confict is assumed to be an exogenous variable whose value (yes/no) may be set by the user at any time. Information on whether Saudi customers support Israel would be another such variable.

[22] OPEC-established posted price under present contractual arrangements.

[23] To do otherwise would require a sophisticated model of bargaining among OPEC members. It is suggested, however, that later versions of the decision module produce information as to the Saudis' predispositions concerning price and production levels which result from their situation. These would be quite valuable to the anticipated user.

CHAPTER VI. REVIEW OF COMPLETE MODEL BY EX-FLAG OFFICERS AND POLICY PLANNERS

The complete model, consisting of the three substantive modules plus the suggested initial decision module, was presented for review to ex-flag officers and policy planners. The substantive modules were described and the decision module's flow talked through after an introductory discussion of the model's intended purpose and its basic approach. Two types of criticism surfaced during these reviews, the first involving specific errors or omissions within the model, and the second involving problems of a more general nature regarding the model's approach.

Specific Criticisms

Upon being told, in response to a question, that Saudi Arabia planned a tenfold increase in its domestic consumption of refined petroleum products, one respondent pointed out that the construction of refineries to produce the required quantities would require capital investment and suggested that such investment be included in the model. Presumably this would also require keeping track of domestic refining capacity over time.

With respect to the question of possible Saudi budget deficits it was suggested that short- and long-term deficits would probably be handled differently by the Saudis and that they should be kept conceptually distinct within the module. It was also pointed out that a military budget allocation could often be used as a source of revenue to cover a short-term deficit because, in many instances, the delivery time of purchased military equipment may be "slipped." This would not, of course, necessarily remove the deficit, but would delay expenditure (perhaps for a year).[24] The time obtained in this fashion could be used to "find" the money somewhere else.

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[24] If a contract were cancelled instead of delivery being pushed back, the deficit might be removed (if enough money were saved).

There was strong criticism of the model's lack of attention to bottlenecks in a developmental economy. In particular, it was pointed out that development, especially industrial development, requires skilled manpower, the need for which did not appear within the model. In addition, even assuming that the model could project manpower needs, there was no way of taking into account either possible bottlenecks in getting personnel trained abroad[25] or the effect of educational expenditures on the number of personnel produced by Saudi schools.

General Criticisms

The general points were raised by the individuals interviewed. First, it was pointed out that the decision module assumed the equivalent of a single decision-maker. In reality the Saudi government has functional ministries, the heads of some of which may be quite influential in making policy within their areas of responsibility, It was suggested that the model could be improved in two ways. First, decision-making within each sector could be more explicitly based on that of the relevant ministry where appropriate. Second, account could be taken of conflicting bureaucratic interests where (and if) they are identified.

The second general point concerned the environment within which Saudi decision-makers function. International political and economic considerations may act as constraints on the feasibility of some Saudi policies. It was recognized that some exogenous influences are included within the model but there was a desire to see additional detail and a more explicit representation of exogenous variables in terms of U.S. and West European policy options.

The last general criticisms raised deal with the way the developmental process was to be conceptualized. It was argued that the process should be

[25] For example, how many students can be trained abroad and in which disciplines? From what base in Saudi Arabia will the students be drawn?

conceptualized roughly as shown in Figure 3. Items above the decision box represent resource inputs to the process. Below the decision box are sectors to which the resources are allocated. At least two of these sectors (oil and education) provide additional inputs for the process in feedback loops. The current model lacks the ability to see the results of resource allocation to sectors other than oil and the ability to allocate non-financial resources. These were considered extremely important shortcomings from the perspective of a policy planner.

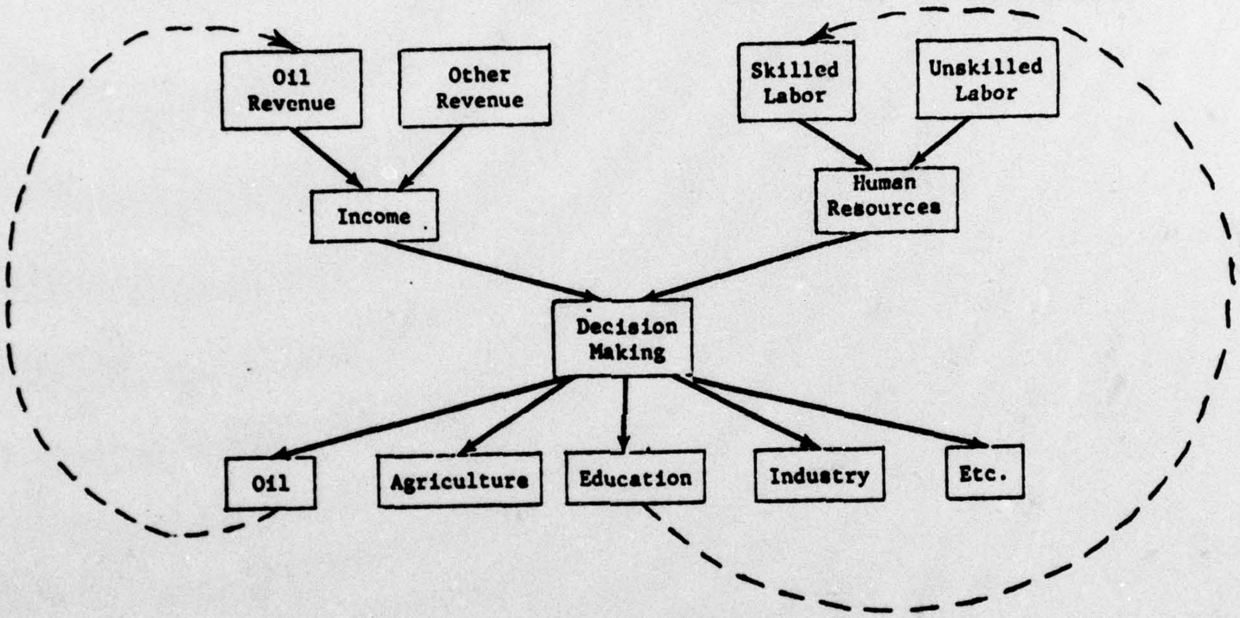

Figure 3. A Policy Planner's View of the Development Process

VII. IMPLICATIONS FOR THE PROJECT'S RESEARCH PRIORITIES

The key problem with the project's model in its present form is its total lack of utility to the policy planner. This point was made rather forcefully when an ex-flag officer suggested that the model simply failed to capture a very critical aspect of the development process. The aspect of which he spoke was the severe bottleneck imposed by a shortage of trained manpower on any effort to develop previously nonexistent (or very small) areas of the economy even when large amounts of capital are available.

In order to capture this problem within the model, the representations of sectors to be developed must contain, in addition to requirements for capital, requirements for trained manpower that are tied to the sector's level of development. The levels of trained manpower available in appropriate categories at any time must be known, and the process that produces trained individuals must be related to the resources (both monetary and human) allocated to it. The human resources module is presently completely unresponsive to the input of resources. Moreover, there is no demand for its outputs (educated and/or trained manpower) elsewhere in the economy.[26]

The implications of these problems for the project's efforts are relatively straightforward but very important. First, a running decision module must be produced, since feedback from policy planners depends upon their seeing a complete model. The structure given in Chapter V of this report should be suitable for an initial effort, provided additional detail is provided in areas where the need was indicated. Second, an industrial sector routine should be produced that contains requirements for both capital and manpower for various levels of development.[27] This sector should specifically

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[26] For an already developed and extremely capital-intensive industry such as oil t:is is not too important. Capital rather than manpower will be by far the greater constraint on reasonable expansion of production capacity.

[27] As indicated in Chapter V, it is envisioned that the industrial sector routine for Saudi Arabia will be developed within the decision module. Only for a nation with a moderately large industrial sector already in existence would the development of an elaborate and independent sector module be appropriate.

include (as a minimum) both petrochemicals and heavy industry. Third, the human resources module should be reworked. Successful and timely completion of these tasks will result in a model that is not a priori useless to a policy planner. Efforts can then focus on tuning the model in accordance with substantive criticism from policy planners.

Two additional points should be kept in mind while the necessary work is being done. First, careful attention should be paid to the possibility of error in statistics and published information about Saudi Arabia. Every effort should be made to examine as much material as possible, to check for contradictions and convergences, and, if possible, to check Saudi data against figures for similar countries. Second, continued and intensive development and refinement of the decision module should provide the focus for the research tasks, and the research effort should be iterative in the sense that questions about the control inputs to (and interactions between) the substantive modules spur further inquiry into the decision process including its guiding goals and priorities.

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Modeling for the Future*

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At least since the publication of Weaver's (1948) well known paper on complexity, many scientists have been aware that the methodological practices employed in studying a problem ought in some sense to be related to the "complexity" of the phenomenon under investigation. Recently Forrester (1969:107) has argued that all social systems belong to the class of complex systems and, as such, "...have many unexpected and little understood characteristics." Some of Forrester's work led to the world modeling project described in <u>Limits to Growth</u>. And, even more recently, Marstrand and Sinclair (1973:89) summarize their critique (with due apologies to Gertrude Stein) of the pollution subsystem of the World models by claiming, "...<u>The Limits to Growth</u> has achieved ... a final simplicity by ignoring all complexity."

It is noteworthy that the concept of complexity is so frequently encountered in discussions of the "holistic" modeling of social systems. Perhaps even more interesting is the relative lack of attention paid to what might be meant by the "complexity" in these context (a notable exception being Nurmi (1974). The purpose of this paper is to consider possible meanings for complexity in a social science context and to discuss implications of these meanings for the development and interpretation of performance measures (e.g., quality of life) for "complex systems."

A useful way to begin may be by summarizing several claims made about complexity beginning with Weaver's argument which first appeared in Weaver (1948) and was later slightly modified in Weaver (1967). Up until the 20th Century, suggests Weaver, physical science was in a period of developing techniques to deal with the analysis of "two-variable problems." Such a problem is illustrated by the way gas pressure (variable one) depends upon gas volume (variable two) in a very major way and upon other variables at most only slightly (at least for a wide range of values of the two variables). Such

problems "...are essentially simple in structure, this simplicity resulting largely from the fact that the theories or the experiments need deal with only two quantities, changes in one of which cause changes in the other. The restriction to two variables and in most cases to simple relations between the variables and their first and second derivatives, kept the theoretical system well within the then analytical and computational capacity of mathematics. Correspondingly, these could be simplicity in the experimental basis; and this simplicity was also a necessary condition for progress at that development of science (1967:26)." Then, roughly at the beginning of the twentieth century, physical scientists and mathematicians began developing and utilizing theoretical tools such as probability theory and statistical mechanics for handling problems with very large numbers of variables. Such problems Weaver terms "problems of disorganized complexity." "It is a problem in which the number of variables is very large, and one in which each of the many variables has a behavior which is individually erratic and may be totally unknown. But in spite of this helter-skelter or unknown behavior of all the individual variables, the system, as a whole, possesses certain orderly and analyzable average properties (1967:29)." The special features of problems of disorganized complexity then are 1) large number of "variables" and 2) the behavior of each "variable" is statistically independent of the behavior of other variables.

What remains, suggests Weaver, is to develop methods for handling problems involving large numbers of variables where the variables "<u>show the essential feature of organization</u> (1967:31)." While this essential feature is not specified in a positive way, presumably Weaver is focusing upon problems where averaging and other statistical techniques are inappropriate or misleading. Such problems he terms problems of "organized complexity." Finally, Weaver

suggests that methods of dealing with organized complexity may be especially useful in the social and behavioral sciences.

Weaver's treatment of complexity seems based upon two characteristics of a problem - one quantitative and one qualitative. The first is the number of variables* and the second is the "way" in which the variables are related. As will be seen, these two characteristics have since been frequently employed to index complexity. Note however that together they require that complexity be seen not as a property of "reality" but rather as a property of our description of "reality." Thus an index of the complexity of a referent reality is an index of the complexity of that reality <u>under some description</u>. This point will be returned to, but first there are several more views of complexity similar to Weaver's "disorganized complexity" which ought be mentioned.

Von Neumann (1966), speculated, "It is characteristic of objects of low complexity that it is easier to talk about the object than produce it and easier to predict its properties than to build it. But in complicated parts of formal logic it is always one order of magnitude harder to tell what an object can do than to produce the object. The domain of validity of the question is of a higher type than the question itself." Unfortunately, von Neumann has left unclear the precise meaning of this enigmatic passage. Clearly though, he has in mind that beyond some threshold complexity level our mode of understanding systems changes. Shaw (1970) uses von Neumann's statement to conclude that "any science, like psychology, which desires formal models of highly complex systems, like organisms, will have to consider von Neumann's conjecture a threat to the fulfillment of its explanatory goals."

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* Though as Nurmi (   ) points out Weaver uses variable in a way somewhat different than would a behavioral scientist.

Forrester (1969) defines complex systems as systems with a "high-order, multiple-loop, nonlinear feedback structure." These systems, claims Forrester, behave very differently from the more simple systems we are used to dealing with. Complex systems, for example, are counter-intuitive, insensitive to parameter changes, and have short-term responses which are very different from their long-term responses.

Levins (1970) views complex systems which have many elements and few constraints on the relations between these elements. It is worth quoting at length his thoughts about such systems:

> Suppose we did know the interrelations among all parts of a system and could describe the rate of change of each variable as a function of the others. Then we would have a very large set of simultaneous non-linear equations in a vast number of variables, and depending on so many parameters, the estimation of each of which may take a lifetime .... These equations will usually be insoluable. They would likely be too numerous to compute. If we could compute, the solution would simply be a number. If we could solve the equations, the answer would be a complicated expression in the parameters that would have no meaning for us.

Based upon treatments such as those just mentioned, it is tempting to conclude that complexity is an "intrinsic" characteristic of a system (or, at least, of a system under a description). From such a perspective it would be possible to (metaphorically) develop a complexity "probe" which could be inserted into a system and from which could be read the "complexity" score of that system. However, there are a variety of reasons why such a conclusion is likely in error and that no adequate characterization of the complexity of a system can be given independent of a specification of the class of systems "dealing" with that system. For example, many living species might be said to be facing a less complex environment now than they did thousands of years ago in the sense that, through evolution, many common relational structures may have been "pre-programmed" into their brains. Such pre-programming through evolution or design may well be a key to any system behaving adaptively in a seemingly "complex environment."

As another example, baby salamanders live completely on land for a time after they are born before entering the water in search of new forms of food. Is their ability to swim learned in some fashion; perhaps by imitating other salamanders or by trial and error? Coghilll (1929) anesthetized a salamander at birth and kept it in this condition for the length of time salamanders had been observed to remain on land before beginning to swim. After this time had elapsed, the salamander was dropped into water. Even though no learning could have taken place, the salamander was able to swim effectively. The reason for the delay between the time of birth and the onset of the ability to swim was that, as a part of the maturation process, a certain neutral connection had to be made in the salamander's spinal cord. The ability to swim is pre-programmed into the developmental process of the salamander. The effect of dropping a one week old salamander into the pool of water would be

very different from that of dropping a five month old salamander into the same pool. Does the complexity of the pool of water change if one animal is able to deal effectively with it while another is not? A more rigorous example drawn from automata theory might make this point more clearly. The problem is to design a Turing maching which can determine whether a string of symbols reads the same backwards as forwards (as in ABLE WAS I ERE I SAW ELBA). Arbib (1969) proves that, for a Turing machine with one reading head the time necessary to decide the problem increases with the square of the length of the symbol sequence. For a Turing machine with two reading heads, however, the time increases only as a linear function of the sequence length. If the complexity of the problem is indexed by the time required to solve it, it is clear that the internal structure of the "solving machine" must be specified rather carefully.

These examples lead to a conclusion similar to that of Nurmi (1974), "Complexity can be viewed as an ontological property of the relationship between the actor and the environment (p. 84)." As long as the focus of study is systems with control structures, complexity must be viewed in a contingent fashion. The next section will suggest implications of this contingent view for theorizing about control structures.

Econometric models are simply mathematical statements of the quantitative relations between variables. Generally these statements are in the form of simultaneous (often linear) equations together with a set of constraints (e.g., certain coefficients must be non negative). In constructing such models, the theorist must specify the form (structure) of the equations as well as the way in which the variables enter the equations. From these equations certain quantitative and qualitative deductions can be made. These include such things as predictions of future levels of endogeneous variables, identification of equilibrium and stability conditions, etc. Figure 1* illustrates the basic mechanism.

Insert Figure 1 about here

The reader is referred to Christ (1967) for a very readable account of the construction of econometric models.

As Christ points out, such models can be guides to choice of policy required to optimize certain utility or welfare functions, if the analyst has a clear statement of the function which is to optimized and also a clear idea of the set of possible policies from which the choice might be made (Theil, 1958). And finally, such a model might be used for simulation studies of the behavior of the system it represents.** There are several dif-

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* Taken from Christ, 1967, p. 104.

** It should be pointed out there there is little to gain from simulations of econometric models when there are analytical solutions available. Four major points are made by Howrey and Kelejian: (1) Once a linearZeconometric model has been estimated and tested in terms of known distribution theory concerning parameter estimates, simulation experiments that are undertaken to investigate the model as an interrelated system yield no additional information about the validity of the model. (2) Although some of the dynamic properties of linear models can be inferred from simulation results, an analytical technique based on the model itself is available for this purpose. (3) The application of nonstochastic simulation procedures to econometric models that contain nonlinearities in the endogenous variables yields results that are not consistent with the properties of the reduced form of the model. (4) The results derived from the stochastic simulation of nonlinear systems are consistent with the corresponding reduced-form equations. (Naylor, 1971, p. 300)

ficulties with this class of modeling, however. Completely simultaneous linear equations, while argued for by some modelers such as Liu (1960) are considered inappropriate because they do not look at the time aspects of the interrelationships. That is, as Wold and Faxer (1957) point out certain pressures affect the growth or stability of a particular variable before others do. Block recursive systems have been developed to deal with this problem (Ando, Fisher, and Simon, 1963). The difficulty with systems of this nature, however, is that forecasts are only as appropriate as the time frame remains short enough to allow for intra-subsystem variance to be more important than inter-subsystem variance.*

Another difficulty in analyzing these models to complex, dynamic issues deal with the frequency with which simplifying linearity assumptions are made. Much of the real world may be nonlinear and while linear models are more tractable than nonlinear ones, realism may require nonlinearity. Two solutions have been put forth for dealing with this problem. The first is to limit the equations to be nonlinear in the variables but not in the unknown parameters. The second is to construct a linear approximation to the model in the neighborhood of the observed values and employ the model to analyze small changes (Netherlands Central Planning Bureau, 1961; Van Den Belt, et al., 1965). Obvious difficulties arise in both approaches, however. The problem of identification in nonlinear systems has not been fully solved and provision must, of course, be made ultimately to avoid working with underidentified equations and systems. One procedure for solving equations in a nonlinear system is by employing ordinary least squares and then using these results as initial approximations to full information solutions. (Eisenpres and Greenstadt, 1969). The difficulty of using such methods is

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* A simplified version of this argument was prepared by Fisher and Ando (1962).

that the reality which policy makers wish to deal with tends to be dynamic. If the variables in our model were always correlated in the same way regardless of the mode of system behavior, then they could always be aggregated together into the model in the same way. But if the correlation between variables changes when the model of the behavior of our system changes, then our models must represent the variables separately during each transition mode. The need for separate representation is not well met in linear or nonlinear econometric models. Realization of the importance of this problem in dynamic modeling has led to the understanding that one cannot use correlation coefficients in the building of dynamic models (Brunner and Brewer, 1971). It has also led scholars such as Forrester (1968) to the development of dynamic multiloop feedback systems.

Dynamic Systems Oriented Simulations

Most attempts to generate an explicit model of foreign policy behavior, on the part of academics, have relied upon linear relations among relatively few variables (e.g., linear regression models and factor analysis). These models have certain advantages over mental images of foreign policy interactions since they have explicitly specified sets of assumptions about the relations between these variables which can be checked by resorting to data analyses. These assumptions of linearity provide fairly accurate short-term (several years) projections since any curve, over a short enough interval, can be approximated by a straight line. However, the longer into the future the projections are made, the greater will be the likely error, just as in the case for trend extrapolation. In designing long-term planning systems, the analyst must be prepared to work with non-linear systems. One problem with non-linear systems is the lack of methods for solving such systems analytically. However, solutions can be reached through the use of computer

simulations.* These simulations provide information about the overtime implications of the defined alternatives. Moreover, they will allow the manipulation of the variables and relations to test the relative, long-range impacts of various policy alternatives. These simulation models to be useful to the policy planner require that the variables be categorized as to whether they are manipulable or non-manipulable and as to whether they are exogenous or endogenous:

1. Manipulable variables are directly controllable by the policy maker.

2. Non-manipulable variables may vary as functions of other variables in the models but are not directly controlled by the policy maker's actions.

3. Exogenous variables effect but are not affected directly by relations specified in the system.

4. Endogenous variables effect other variables and are in turn affected by other variables in the system.

A set of variables representing each subset of manipulable exogenous, non-manipulable endogenous, and non-manipulable exogenous variables can be posited. The variables and relations could, in part, be identified by people involved in the policy process and could be used to construct simulations.

Thus, within the system, each variable would be in one of the following vectors:

$M^{x}i$ = vector of manipulable exogenous variables

$U^{n}i$ = vector of non-manipulable endogenous variables

$U^{x}i$ = vector of non-manipulable exogenous variables

These variables are related by some set of relations, f. Thus:

$$f(M^{x}_{i}, U^{n}_{i}, U^{x}_{i}) = \text{"The System"} \quad (5)$$

* See the very interesting debate between Nordhaus (1973) and Forrester, et al. (1974) on the use of such an approach.

Models of this nature consist essentially of a large set of mathematical equations which are programmed into a computer. Projections into the future are simply the implications of the assumptions on which the equations rest. The value of extrapolation is determined completely by the validity of the assumptions that went into the building of the model. They drive the results mechanically. Their validity, however, depends on the descriptive adequacy of "the system" and on the empirical domain to which the model is applied. The adequacy of the system is governed by two considerations: (1) available knowledge of how the included variables interact raises a serious question as to the state of preparedness for this type of model of most of the social sciences today. The other condition relates to the presence of all variable factors that significantlyzaffect the interacting behavior of the other variables. This particular aspect of dynamic modeling leads us to question the adequacy of the approach. We can take up these two criticisms in their order.*

Social scientists do not yet possess a body of theory sufficiently developed and tested to permit the confident specification of variables to be included, form of equations to be used, and appropriate lags for each variable prior to the estimation of parameters entering into equations. Existing theory offers some guidance, but it is the most fanciful kind of wishful thinking to believe that it offers much guidance in the above respects for many of the political problems which face decision makers in the policy oriented future. This being the case, it is obvious that any effective testing and estimation does require veryzlarge numbers of observations. This would be true even if the observations to be used were generated by experiments

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* For a comparison of a number of modeling techniques and their application in political economic forecasting see Heiss, Knorr and Morgenstern, Long Term Projections of Power (1973).

arranged according to the best available knowledge about experimental design.*

Perhaps the greatest challenge in mathematical modeling and simulation is to select a model large enough to represent a real situation realistically, but small enough so that it can be tested by experiments and observations. Given our state of knowledge about the relations between numerous variables, this leads us quickly into difficulty. One solution frequently used in international relations has been to move to highly aggregated forms of data. But such highly aggregative series do not begin to contain enough degrees of freedome to permit extensive testing and estimation. This would be true even if the observations in such a series resulted from well-planned experiments. In fact, most available aggregative series are highly auto-correlated, highly multi-colinear, are frequently poor measures of what we want to measure and do not measure short run developments. They are involved in an operating system involving many relatively rapid feedbacks. All this only compounds the already apparent drawbacks of estimation and testing based only on highly aggregative time series.**

This issue is perhaps best handled by E.A. Singer (1960). He argues that reality is an ideal, and unobtainable description of the world. But like all ideals, it can be approximated. A formal system is an approximation if it meets certain requirements: It must be consistent, the data must be statistically in accord, it must be rich enough to include space, time, motion, mass, mind, group, and value. It must also be significant in the sense that it directs inquiry into its own deficiencies, so that a better approximation

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* Several new articles are appearing which provide alternative methods for estimating parameters from empirical data for this type of model building. See, for instance, Hauser and Goldberger, 1971.

** The classic reference is Theil, 1954.

is made possible. In other words, its language and rules must include criteria of better and worse approximations, i.e., degrees of realism.

Singer is certainly not claiming that all practical work must contain the whole of reality. Rather, he argues that each researcher will construct a subsystem adequate to his own needs for a particular period in time. But the lines of communication have to be kept open in the sense that it is always relevant to ask whether two subsystems should not be combined in order for a single researcher to cover larger periods of time or for several researchers to answer several intertwined sets of problems. There may be a temporary way out of this problem. Returning to Figure 1, our stylized schematic and development of a model, in which inputs to the model in the form of exogenous and lagged endogenous variables and outputs in the form of current endogenous variables were the organization framework for discussing models. Another possibility involves describing the system in automata theoretic terms. Following Arbib (1964) such a specification involves:

$$\text{The System} = (U, Y, X, \lambda, \delta)$$

where:

U is a finite set (the set of inputs partitioned as in equation (5))

Y is a finite set (the set of outputs)

X is a finite set (the set of internal states)

$\lambda: U \times X \rightarrow X$ is the next-state function

$\delta: U \times X \rightarrow X$ is the next-output function

Such systems are assumed to work on a discreet time schedule so that if at time t it is the state x and redeives an input u then at time t plus one it has changed to state $\lambda(x,u)$ and emits output $\delta(x,u)$.

Clearly it is desirable to identify what the state transition functions are if we wish to estimate future shifts in behavior in our policy problem.

This requirement can be illustrated by a simple example. Consider the behavior of a "bully" nation. Suppose it is capable of being in only two internal states--it either is stable (S) or unstable (~S). Further, it is capable of emitting and sensing only two sorts of behaviors--aggressive (A) and non-aggressive (~A). Thus we have:

u: {A,~A}

y: {A,~A}

x: {S,~S}

Since the nation is a bully, it will behave aggressively whenever it can. And yet the only time a bully does not aggress is when it is aggressed upon and in a weak (in our terms unstable) state. Thus we can write y= (x,u) as in Table 1.

Table 1

Input (u)	State (x)	Output (y)
A	S	A
~A	S	A
A	~S	~ A
~A	~S	A

As can be seen the output of the bully nation is entirely deterministic. Further, since even a bully becomes unstable when aggressed upon, $\underline{x} = \lambda(\underline{x},\underline{u})$ can be written as in Table 2.

Table 2

Input (u)	State (x)	New State (x)
A	S	~S
~A	S	S
A	~S	~S
~A	~S	~S

All this most likely seems both absurd and simple. However, further suppose a political scientist is watching the bully nation and trying to relate its behavior (outputs) to the behavior it receives (its input). What will he see?

First of all, he will generally ignore the internal structure of the system and simply relate inputs and outputs. Thus he might watch the bully over a long period of time and note that non-agressive inputs always are followed by aggressive outputs on the part of the bully. However, he would note, aggressive outputs are preceded by aggressive inputs only about one half of the time. Therefore, he writes an article in which he proclaims two general laws.

$$\text{law (1)} \quad P(y = A|u = \sim A) = 1$$

$$\text{law (2)} \quad P(y = A|u = A) = 1/2$$

Of course, by this time the world is getting rather sick of the bully's behavior and commissions our political scientist to recommend a policy toward the bully (this policy above, the optimal policy would, of course, be to always behave in an aggressive way toward the bully nation which would, according to law (2), guarantee that 1/2 of the bully's responses would be non-aggressive.

Note that our mythical political scientist, like so many of us, ignored the internal state of the bully nation. As a result, he was forced to state his laws in probabilistic terms and to conclude that the "best" that could be done was to reduce $p(y = A)$ to about one half.

However, by referring back to the transition tables, it can be seen that the bully can be made to act in a completely non-aggressive way. Suppose first he is initially in state $\sim S$. Then by always behaving in an aggressive way toward the bully, the bully will never respond in an aggressive way. If, on the other hand, he is initially in state S, then he will respond in an aggressive manner no matter what you do. However, by threatening him, you will force him into an unstable state and therefore continuing aggressive acts will

result in no more threats from the bully.* Thus, paying attention to internal states, it is possible to eliminate references to probabilities and to suggest a policy which will result in at most one aggressive behavior by the bully. While in this example ignoring internal structure did not result in "wrong" policy advice, it is possible to construct a slightly more complex example for which it would.**

The important point here is that developing descriptive theories of policy behavior requires paying close attention to the internal structure of the foreign policy generating mechanism as well as to that of the environment (domestic as well as international) in which the mechanism is imbedded. We need to know how inputs affect internal states and how inputs together with internal states determine outputs. As Halperin and Kanter (1973, p.3) suggest, "....the scholar requires an understanding of a nation's domestic political structure and of its national security bureaucracy in order to explain or predict the foreign policy actions it will take." At this point in the development of research in social science, we also need, however, to identify the differences in a finite set of states or subsystems which have been identified as potential explanatory structures for understanding of policy problems. We need also to better understand the implications of policy actions in each state of the system (thus, we need to devote understanding of $\delta: S \times X \to Y$.

This approach is based upon finite state automata theory and has a strong argument in its favor. That is, it requires the precise specification of the functional relationships between endogenous and exogenous variables for producing estimates of the output.

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* Though such a policyzmight result in your becoming a bully.

** For example, see Kanter and Thorson (1972).

What has been presented here are three alternative approaches to modeling major policy problems for the future. It is suggested that econometric models and dynamic forecasting models both are in need of continued development. Both have difficulties. The former suffers from an inability to deal with large scale, long-range forecasting and decision oriented problems. The latter suffers from an inability to provide significant validation checks on the empirical validity of subrelations within the model. The solution is to move to partial answers based upon the notion that the structure of our theory undergoes shifts given both the current state of the system and the particular shocks in the form of input variables that the system is experiencing. But once we have such a model we still are left with a series of general questions which must be addressed by all such models. Brewer and Hall (1972) suggest the following checklist.

1. Is the distortion between the model outputs and what the policy maker is looking for so large that the model is rejected out of hand? Can this be reduced? At a reasonable cost in time, effort, and money?

2. Are the model's output and input generally intelligible; are they in a form that is familiar to the policy maker?

3. Does the model offend "common sense?"

4. Are elements of the identified question excluded in the interests of generalization or precision?

5. Is the model static and descriptive in the interest of simplification?

6. Is it possible to include submodels or to change individual behavioral relationships that appear to have a bearing on the policy questions without destroying the processing or the logic of the model or without significantly increasing its operating cost?

7. Are relevant variables, as determined empirically and by virtue of sensitivity testing, omitted in the interest of precision or expense?

8. Is the model able to predict, through reconstruction, the time series upon which it is formulated? Has it been able to predict time series from the reference context developed subsequent to the model's formulation?

9. If there are known structural changes in the empirical context, are provisions made in the model to capture these? I.e., If there are increasing numbers of disaggregations, changing parameters, or precipitating discontinuous events in the context, are these taken into account? Or, are these events ignored or assumed away?

10. Are the policy interpretations of various model entities, structures, and recommendations, consonant with the ethical-moral and professional standards of the policy makers and the affected *population*? (*Brewer and Hall*, 1972: 18-19).

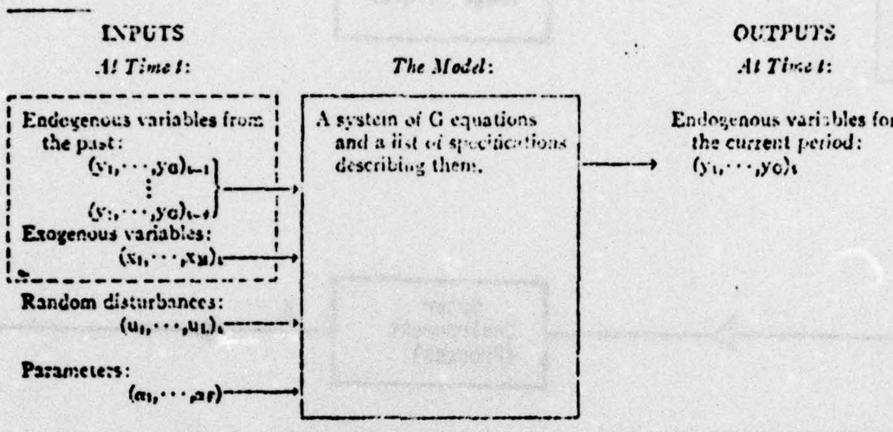
INPUTS
At Time t:
The Model:
OUTPUTS
At Time t:
Endogenous variables from the past:
$(y_1, \cdots, y_G)_{t-1}$
$(y_1, \cdots, y_G)_{t-k}$
Exogenous variables:
$(x_1, \cdots, x_K)_t$
Random disturbances:
$(u_1, \cdots, u_G)_t$
Parameters:
$(\alpha_1, \cdots, \alpha_P)$
A system of G equations and a list of specifications describing them.
Endogenous variables for the current period:
$(y_1, \cdots, y_G)_t$

Figure 1.

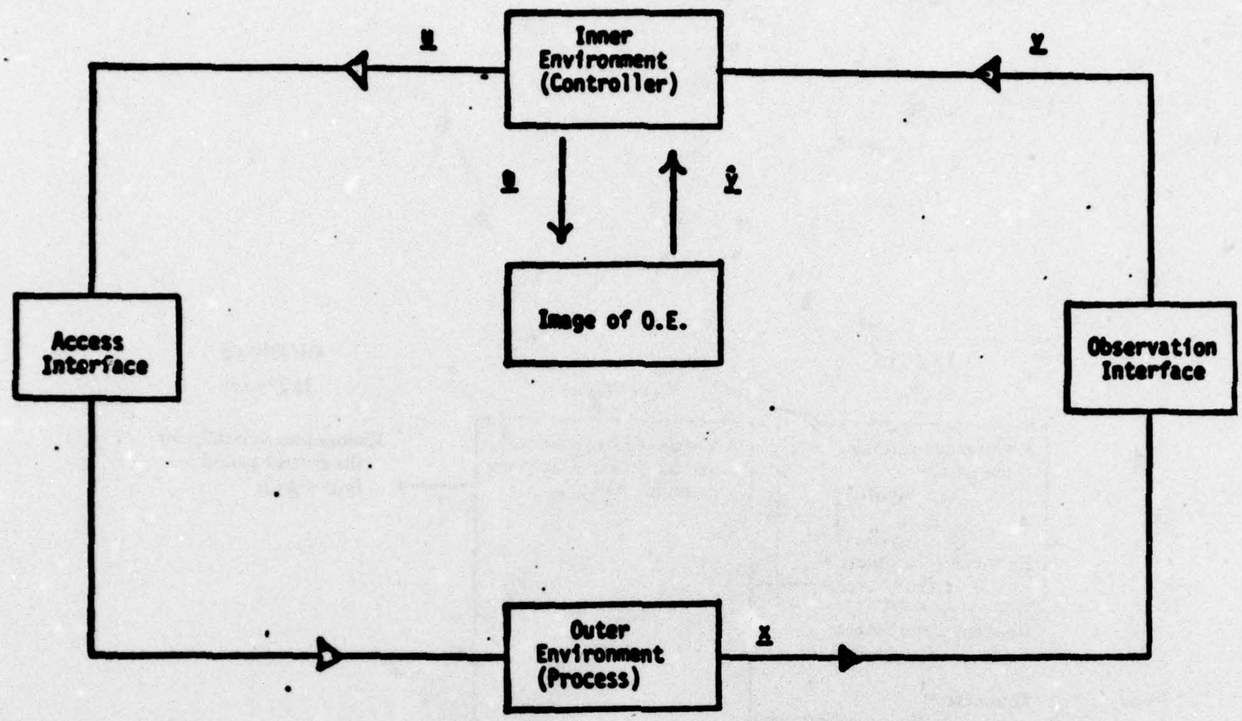

Figure 1 Artificial System Structure

```
PS:  LRCC74
STI: (NIL  NIL  NIL  NIL  NIL  NIL  NIL  NIL)

1:  (STOP) → END
2:  (REQUEST) → (OUTPUT  "RESIGNATION", STOP)
3:  (MARK,MARK,MARK,MARK) → (OLD(**),REQUEST)
4:  (FOOD SHORTAGE,FISCAL IRRESPONSIBILITY,NEGATIVE FOREIGN
        COMMENT BY AN ALLY) → (OLD(**),REQUEST)
5:  (FOOD SHORTAGE) → (OLD(**),MARK)
6:  (SUPPORT OF RADICAL FOREIGN CAUSES,NO ACHIEVEMENT) →  (OLD(**),MARK)
7:  (SUPPORT OF RADICAL FOREIGN CAUSES,SFRC,SFRC,SFRC) →  (OLD(**),
        FISCAL IRRESPONSIBILITY)
8:  (FISCAL IRRESPONSIBILITY) → (OLD(**),MARK)
9:  (NEGATIVE FOREIGN COMMENT BY AN ALLY → (OLD(**),MARK)
10: (BAN CIGARETTES or BAN ALCHOHOL or BAN LUXURIES) →
        (OLD(**),ORTHODOXY)
11: (ORTHODOXY,ORTHODOXY,ORTHODOXY,ORTHODOXY) → (OLD(**),MARK)
12: (FOOD SURPLUS,MARK) → (OLD(**))
13: (SUPPORT RADICAL FOREIGN CAUSES,ACHIEVEMENT,MARK) → (OLD(**))
14: (INCREASE IN SKILLED LABOR,MARK) → (OLD(**))
15: (SADAT HAS TROUBLES,MARK) → (OLD(**))
16:  → READ

* SFRC = SUPPORT OF RADICAL FOREIGN CAUSES
```

Figure 2 A Simplified Production System

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Report on Saudi Arabian Decision
Procedures as Viewed in Set-Function Form*

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What follows is a set theoretic specification of the Saudi Arabian decision making procedure. This incorporates Tamashiro memos of October 5 and November 3, Buss memo of July 29, and undated Miller memo.

dfn: S = {set of sentences}

dfn: C = {bits of information internal to Saudi decision making}

The elements of the above defined sets are listed below. The elements are indexed with the natural numbers where an index for a set ranges from one to p (p finite).

MILITARY SENTENCES

Ms0: Nation x (either Israel, Iran, Kuwait, Syria, Iraq, UAR, United Emirates) increases military capability and is not an ally of Saudi Arabia.

Ms5: A new military alliance (including either Israel, Iran, Kuwait, Syria, Iraq, UAR, United Emirates, but not Saudi Arabia and not the US) appears on the world scene.

Ms6: Saudi allies and/or friendly states block covert or overt military operations directed against Saudi Arabia through the use of political pressure and/or direct military assistance.

Ms10: Nation x (either Israel, Iran, Kuwait, Syria, Iraq, UAR, United Emirates) mobilizes, places armed forces on alert status, or conducts large-scale military maneuvers and is not an ally of Saudi Arabia.

Ms15: Nation x conducts overt or covert military operations against Saudi Arabia, which cannot be stopped.

Ms17: Nation x conducts overt or covert military operations against Saudi Arabia.

Ms20: Nation x breaks diplomatic relations with Saudi Arabia.

Ms25: The US is willing to provide arms.

Ms30: The Soviet Union threatens and/or breaks off diplomatic relations with Saudi Arabia.

Ms35: A Warsaw Pact state actively aids a Saudi insurgent group or national, regional opponent.

Ms40: No Warsaw Pact state is actively aiding a Saudi insurgent group or national, regional opponent.

Ms45: The US is unwilling to provide arms.

Ms50: Some western nations (e.g., Britain, France, Sweden) are willing to sell arms.

Ms55: No western state is available as an arms source.

Ms56: SA has security ties with US or other western powers.

Ms60: A Communist bloc state is available as an arms source.

Ms61: Saudi Arabia has no security ties with the US or other western powers.

Ms65: No Communist bloc state is available as an arms source.

Ms70: The US formally guarantees Saudi security, no insurgent groups operate within Saudi borders and all Middle Eastern states sign treaties of friendship with SA.

Ms75: Insurgent groups operate within Saudi borders with aid from nation x (either Israel, Iran, Kuwait, Syria, Iraq, UAR, United Emirates).

Ms80: The US withdraws political and/or military support from Saudi Arabia.

Ms85: A major arms supplier for Saudis (other than the US) refuses to continue sales.

Ms90: Consult US Defense and State Departments about arms sales, military advisors, etc. Actively lobby for such sales in US bureaucracy if necessary.

Ms95: Purchase arms and strengthen political ties via increased diplomatic visits and consultations, cooperative effort or other outstanding issues.

Ms96: Saudis reject initial arms price and propose counteroffer (budget module gives counteroffer in $).

Ms100: Strengthen political ties with Arab allies via aid, political consultations, public displays of friendship, etc.

Ms105: Seek political ties with the US and other western powers with the aim of gaining security guarantees.

Ms110: Maintain existing political ties with the US and other western powers for security guarantees.

Ms115: Attempt to placate unfriendly state(s) via negotiations, trade concessions, etc.

Ms116: Unfriendly state(s) refuse to negotiate or reach an agreement.

Ms117: Warsaw Pact states refuse to negotiate or reach an agreement.

Ms120: Seek Warsaw Pact security guarantees (e.g., military interaction, political support in international forums) in exchange for trade concessions, the acceptance of large numbers of technicians and advisors and leases for bases.

Ms125: Cancel defense contracts totalling $x (action taken for long term deficits - $x provided by budget module)(update "old" c125).

Ms126: Delay arms deliveries totalling $x (action taken for short term deficits - $x provided by budget module).

Ms130: Consult Britain, France, Sweden, or any other western nation over arms purchases.

Ms135: Approach Communist bloc state(s) for arms, keeping political ties to a minimum.

Ms140: Purchase Communist arms in gradual increments to avoid a large influx of Communist advisors and technicians.

Ms145: No cuts in defense spending are to be made.

Ms146: The US refuses to restore suspended military and/or political support.

Ms301: ((AGENT)$)): SA will not purchase arms worth $ from agent at this time because of budget uncertainty.

Ms302: ((AGENT)$)): SA will cancel arms purchases worth $ from agent because of lack of revenue.

MILITARY STATE KNOWLEDGE

MC0: Nation x is hostile.

MC5: Significant military threats to Saudi security exist.

MC10: Saudi king believes present Saudi defense capability is not adequate.

MC11: Saudi king believes present Saudi defense capability is adequate.

MC15: A suitable manpower pool (officer corps., military-civilian technicians, military-civilian administration) exists or will exist in the next 5 years to support an expanded defense program.

MC20: Revenues, which could be absorbed in non-military programs or investments exist to finance an expanded defense program.

MC21: The budget bureau wishes to invest in an expanded defense program as a means of using excess revenues.

MC25: The US is willing to provide arms (user provides $ amount)(update "old" c25).

MC26: Saudi Arabia will buy arms from x.

MC28: x aids a Saudi opponent.

MC30: A suitable manpower pool (officers, military-civilian technicians, military-civilian administrators) doesn't exist and won't appear in the next five years to support an expanded defense program.

MC35: Security ties with the US and/or other western powers exist.

MC40: Security ties exist neither with the US nor with other western powers.

MC45: The Saudi king believes existing political security guarantees and ties with friendly nations don't offset military threats to Saudi security.

MC46: Saudi king believes existing political security guarantees and ties with friendly nations offset military threats to Saudi security.

MC50: Previous attempts to placate unfriendly state(s) via negotiations, trade deals, etc. have failed.

MC55: Overtures to the Warsaw Pact states for military/political assistance are unsatisfactory (either because of outright rejections or insufficient assistance).

MC60: Warsaw Pact states are politically unsuitable as sources of assistance (e.g., because they pose either a direct threat or an indirect one via sponsorship of a Saudi regional opponent).

MC65: The Warsaw Pact states are politically accessible as sources of assistance. (i.e., they pose no security threat, either directly or indirectly via the sponsorship of a Saudi regional opponent).

MC70: The US is unwilling to provide arms.

MC75: Britain, France, Sweden, or other western arms source, excluding the US, is available as an arms source (user provides $ amount) (update "old" c75).

MC80: Britain, France, Sweden, or other western states are not available as arms sources.

MC85: The Communist bloc is willing to provide arms (user gives $ amount).

MC90: The arms deal with the Communist bloc is not possible.

MC95: A long term budget deficit exists. The budget bureau proposes a $x defense cut (user provides $x amount)(update "old" c95).

MC96: A short term budget deficit exists. The budget bureau proposes an arms delivery delay involving $x ($x provided by budget module).

MC100: Saudi king believes Saudi national security is not threatened.

MC105: No budget deficit exists (this doesn't necessarily imply revenues exist to finance an expanded defense program; it only ensures that defense spending won't be cut).

MC110: A nation important to Saudi national security (other than the US) has withdrawn its support.

MC115: Revenues do not exist to finance an expanded defense program.

MC125: (transition term) Interpretation: a significant military threat exists for which present defense capabilities are inadequate. However, a potential manpower pool and revenues exist to support an expanded defense program.

MC130: (transition term) Interpretation: a significant military threat exists for which present defense capabilities are inadequate. Further, the manpower pool cannot support an expanded defense program. However, security ties with US and/or other western power exist.

MC135: US withdraws political and/or military support from Saudi Arabia.

MC140: Overtures to the US to restore suspended military and/or political support fail.

MC145: (transition term) Interpretation: a significant military threat exists for which present defense capabilities are inadequate. Further, the manpower pool cannot support an expanded defense program and no security ties exist with the US or other western powers.

MC150: (transition term) Interpretation: a significant military threat exists for which present (or projected) defense capabilities are inadequate. Further, despite the existence of security ties with the west, these security guarantees don't offset the military threat.

MC155: (transition term) Interpretation: a signifncant military threat exists for which present (or projected) defense capabilities are inadequate. Further, existing security ties with the west don't offset the threat, and the Warsaw Pact states are politically unavailable as sources of assistance. Finally, past efforts to deflect the threat via negotiations have failed.

MC160: (transition term) Interpretation: a significant military threat exists for which present (or projected) defense capabilities are inadequate. Further, existing security ties with the west don't offset the threat, and past efforts to deflect the threat via negotiations have failed. However, the Warsaw Pact states are politically accessible as sources of assistance.

MC165: (transition term) Interpretation: a significant military threat exists for which present (or projected) defense capabilities are inadequate. Both the west and Warsaw Pact states have been approached for military/political aid; but the results are unsatisfactory. Finally, past efforts to deflect the threat via negotiations have failed.

MC170: (transition term) Interpretation: a significant military threat exists for which present defense capabilities are inadequate. However, a potential manpower pool and revenues exists to support an expanded defense program. Unfortunately, the US is unwilling to provide arms.

MC175: (transition term) Interpretation: a significant military threat exists for which present defense capabilities are inadequate. However, a potential manpower pool and revenues exist to support an expanded defense program. Unfortunately, the US, Britain, France, Sweden, and other western sources are unavailable as arms s urces.

MC180: (transition term) Interpretation: the US withdraws its political and/or military support.

MC185: (transition term) Interpretation: the US withdraws its political and/or military support and the remaining political guarantees enjoyed by the Saudis from other states aren't sufficient to safeguard Saudi security from external threats. Attempts to end suspension of security ties with the US have failed.

MC190: x is currently attacking SA.

MC195: The budget bureau rejects US arms sale price and offers the following counterproposal (user provide counterproposal price in $).

MC200: US guarantees Saudi security.

MC210: SA asks US to resume support.

MC220: Attempt to placate hostile actors.

MC270: No cuts in defense spending are to be made.

MC290: The budget bureau approves the arms sale with the US.

MC291: The budget bureau approves the arms sale with the western arms source (Britain, France, or Sweden).

MC292: The budget bureau approves the arms deal with the Communist bloc.

MC295: US arms purchase not ok'ed.

MC296: Budget bureau rejects western (other than US) arms sale price and offers counterproposal (user provides counterproposal price in $).

MC297: Budget bureau rejects Communist bloc arms sale price and offers the following counterproposal (user gives counteroffer in $).

ECONOMIC SENTENCES

ES1: SA threatens to cut off aid to x because of support of I.

ES2: SA cuts off aid to x.

ES3: SA gives aid to x.

ES4: SA will increase price of oil if x continues to support I.

ES5: SA increases price of oil to x by .

ES6: SA will reduce oil supply in response to x's support of I.

ES7: Supply of oil to x cut by 50 percent.

ES8: SA threatens embargo of x.

ES9: SA embargoes x.

ES10: SA will cut aid to x unless x opposes I.

ES11: SA threatens to take capital out of x.

ES12: SA transfers liquid assets from x to y.

ES13: SA lifts oil embargo.

ECONOMIC STATE KNOWLEDGE

EC1: *x supports I's position.

EC2: *I is aggressive.

EC3: x receives aid from SA.

EC4: Aid cutoff threat to x.

EC5: *x continues to support I after aid cutoff.

EC6: *x pressures I to "cooperate."

EC7: SA cutoff aid to x.

EC8: SA threatens credit restrictions for oil purchases.

EC9: Cash must be paid for on

EC10: *x supports I after credit restriction.

EC11: *I is not aggressive.

EC12: Threaten supply reduction.

EC13: *x supports I even after supply reduction threat.

EC14: Supply of oil cut.

EC15: *x supports I even after supply cut.

EC16: *x supports I even after embargo threat.

EC17: Embargo of x.

EC18: *x condemns I behavior.

EC19: *x maintains its neutrality vis-a-vis I.

EC20: *x is an unacceptable place for SA foreign investment for political reasons.

EC21: SA has liquid assets in x.

EC22: Threat to take the money out of x.

EC23: *y is an acceptable investment place for political reasons.

EC24: *y is an acceptable investment place for economic reasons.

EC25: Transfer investments from x to y.

EC27: *I is intransigent - but not violent.

EC28: Moderate level of aid to Middle East Arabs.

EC29: High level of aid to Middle East Arabs.

EC30: *International economy is very unstable.

EC31: Lift embargo for economic reasons.

EC32: Lift embargo for political reasons.

EC33: *I has changed to coop.

EC34: US should not be prime arms army source for SA.

EC35: Embargo threat to x.

EC36: *x continues to support I, even after threat of transfer.

EC37: *x continues to support I even after threat of credit end.

OIL STATE KNOWLEDGE

DEMAND(NUMBER): daily demand for oil in barrels

PAPC(NUMBER): production as a per cent of capacity.

COST(NUMBER): expenditure for current fiscal year (updated monthly)

DPIR(NUMBER): desired production increased rate.

L.PC(NUMBER): last month's production capacity.

TOTREV(NUMBER): total revenue for year (updated monthly).

EXCESS.CK.: in short term image if program has already checked for excess production capacity.

ONE.CK.: in short term image if program has checked if Saudi Arabia is pumping at or above capacity.

REV.CK.: in short term image if revenue projections have been completed.

PSET: in short term image if simulation has checked whether proven reserve will last 15 years.

PSTOP: in short term image if reserves will not last 15 years.

REV.TOT.: in short term image if current revenues (TOTREV) have been incremented.

DSET: in short term image if desired production rate (DPIR) has been updated.

PADJ: in short term image if production as per cent of capacity (PAPC) has been adjusted according to world demand.

AGRICULTURAL STATE KNOWLEDGE

IRRG: budget for irrigation

MECH: budget for mechanization

FERT: budget for fertilizer

MECH.YLD: maximum yield given specific level of mechanization.

FERT.YLD: maximum yield given specific level of fertilization.

YMECH: level of mechanization.

YFERT: level of fertilization.

GVPMECH: government price for mechanization.

GVPFERT: government price for fertilizer.

IRRW: current irrigated wheatland size.

ATP: available tractor power.

CUT(NUMBER): $ amount budget section wants ag. to cut its budget.

OK: budget module has approved agriculture's budget.

AG.FINAL: agriculture's lowest possible budget.

HUMAN RESOURCES STATE KNOWLEDGE

maintain (#): cost of maintaining current levels in Human Resources.

wheat (#): current domestic demand for wheat.

AG(#): number of people in "self-employed in agriculture" sector.

PET(#): number of people in "petroleum workers" sector.

expand (#): cost for expanding Human Resources.

milit(#): cost of increasing the military.

cut(#): amount budget module wants Human Resources to cut its budget.

O.K.: budget module O.K. is Human Resources budget.

HRC1(year): military personnel inadequate.

HRC2(year): Saudi bureaucracy inadequate.

HRC3(year): Saudi educational system inadequate.

HRC4(year): too few petroleum workers.

HRC5(year): too few agricultural workers.

HRS1: X(Israel, Iran, Kuwait, Syria, Iraq, . . .) increases military capability and is not an ally of SA.

HRS2: Allocate appropriate expenditures to induce persons from a) unstructured pool to enter enlisted forces, and b) secondary school to enter officer corps (i.e., in total transition matrix raise (11,1) by .0004, lower (1,1) by .0004, and raise (11,4) by .0048 lowering (7,4) by .0048.

HRS3: Allocate expenditures appropriate to induce persons from unstructured pool to become petroleum wage earners. (i.e., raise (8,1) by .000171 and lower (1,1) by .000171).

HRS4: Induce persons in unstructured pool to enter ag land reform (raise (14,1) .0002 and lower (1,1) .0002).

HRS5: Allocate appropriate expenditures to induce persons from teacher training to enter civil service (i.e., change total transition matrix (10,5) raised by .005 and (5,5) lowered by .005.

HRS6: Growth rate of Saudi educational system inadequate to meet demands placed on manpower. Allocate appropriate expenditures to boost educational system growth rate. (i.e., raise (2,1) by .002 and lower (1,1) by .002, raise (5,3) by .09, lower (15,5) by .09.

HR.FINAL: lowest possible budget for Human Resources (put in budget module).

BUDGET STATE KNOWLEDGE

B.PROJ(NUMBER): projected revenues for fiscal year.

REV(#): revenues for current fiscal year.

MC295: don't buy arms from U.S.

MC291: buy arms from Western European source.

MC290: buy arms from U.S.

MC296: do not buy arms from western source.

MC292: buy arms from Warsaw state.

MC297: do not buy arms from Warsaw state.

B.C1: Israel is not hostile.

AG(#): agriculture budget.

FA(#): foreign aid.

HR(#): human resources budget.

DM(#): development and miscellaneous budget.

MIL(#): military budget

Group1(#): sum of budgets for priority sectors.

Group2(#): sum of budgets for lower priority sectors.

B.C2: international economy is unstable.

B.C6: budget items > revenues

B.C7: Group1 > revenues

B.C4: (Group1+Group2 > revenues)

B.report: budget is finished.

B.C9: all Group2 members have minimum budget.

SYNTAX ANALYSES: SENTENCES → SEMANTIC KERNALS

1. Transfer(from,to,what)/positive or negative, present or future, sentence type (declarative or interrogative), speaker.

2. Support(from,to,what)/positive or negative, present or future, sentence type (declarative or interrogative), speaker.

3. Force Display(from)/positive or negative, present or future, sentence type (declarative or interrogative), speaker.

4. Attack(from,to)/positive or negative, present or future, sentence type (declarative or interrogative), speaker.

5. Recognize(from,to)/positive or negative, present or future, sentence type (declarative or interrogative), speaker.

6. Align(actors,type)/positive or negative, present or future, sentence type (declarative or interrogative), speaker.

7. Rate(of what, numeric value)

8. Level(of, numeric value)

INTERPRETATIONS SK = semantic kernel
c = conditions

I: SK → C

I. Transfer kernels - Arms - Present
  A. Positive
    1. Declarative
      a. if AG2 is in Middle East and is not an ally of Saudi Arabia then MC5 and MC0(AG2).
      b. if AG1 is a member of Warsaw Pact and MC0(AG2), then MC60 and if MC85 then not MC85.
      c. if AG2(Israel) and EC4(AG1) then mask EC4(AG1)EC5(AG1)
      d. if AG2(Israel) and EC8(AG1) then EC37(AG1)
      e. if AG2(Israel) and EC9(AG1) then EC10(AG1)
      f. if AG2(Israel) and EC12(AG1) then EC13(AG1)
      g. if AG2(Israel) and EC14(AG1) then EC15(AG1)
      h. if AG2(Israel) and EC35(AG1) then EC16(AG1)
      i. if EC17, ¬ EC5, ¬ EC10, ¬ EC13, ¬ EC15, ¬ EC36, ¬ EC37, ¬ EC16 all (AG1) then EC1.
      j. if MC190(AG2) then MC5.
      k. if AG2 is hostile then MC28.
      l. if Saudi Arabia is AG2 and MC26(AG1) then not MC26(AG1).
    2. Interrogative
  B. Negative
    1. Declarative
      a. if AG2(Saudi Arabia) and AG1(Western European power) then AG1 on "will not sell" list.
      b. if Britain, France, Sweden all on list then MC80.
      c. if AG1(U.S.A.) and AG2(S.A.) and MC210 then not MC210 and MC140 and if MC26(U.S.A.) then not MC26.
      d. if AG1(U.S.A.) and AG2(S.A.) then if MC70 and MC135 and not MC140 and if MC25 then mask MC25.
      e. if AG2(S.A.) then if MC85(AG1) then mask MC85(AG1) or if MC75(AG1) then mask MC75(AG1).
      f. if AG2(S.A.) and AG1 is ally of S.A. but AG1 is not U.S.A. then MC110.
      g. if AG1 is member Warsaw Pact and AG2(S.A.) and MC175 then MC55.
      h. if AG2(Israel) then EC18(AG1).

II. Transfer kernels - Arms - Future
  A. Positive-Declarative (all)
    1. if AG1(U.S.A.) and AG2(S.A.) then MC25
      a. and if MC140 then mask MC140.
      b. and if MC70 then mask MC70.
      c. and if MC180 then mask MC180.
      d. and if MC135 then mask MC135.
    2. if AG1(Warsaw Pact member) and AG2(S.A.) MC85.
    3. if AG2(S.A.) and AG1(Western European Nation) if MC80 then mask MC80 and MC75.
    4. if AG1(ally of S.A.) and AG2(S.A.) and MC190 then MC46.

III. Support kernels
   A. If economic or military support then treat as physical transfer.
   B. Declarative (all) Positive
      1. if AG2(Israel) then if EC4(AG1) then mask EC4(AG1) and EC5(AG1)
      2. if EC8(AG1) then mask EC8(AG1) and EC37(AG1)
      3. if EC9(AG1) then mask EC9(AG1) and EC10(AG1).
      4. if EC12(AG1) then mask EC12(AG1) and EC13(AG1).
      5. if EC14(AG1) then mask EC14(AG1) and EC15(AG1).
      6. if EC35(AG1) then mask EC35(AG1) and EC16(AG1).
      7. if not EC17, not EC5, not EC10, not EC13, not EC15, not EC36, not EC37, not EC16 all (AG1) then EC1
   C. Declarative-Negative
      1. if AG1(U.S.A.) and AG2(S.A.) then MC135.

IV. Force kernels
   A. Declarative-Positive
      1. if AG1(in Middle East) and AG1 not an ally then MC5 and MC0 and AG1 on hostile list.
      2. if AG1(Israel) and BC1 then mask BC1.

V. Attack kernels
   A. Declarative-Positive
      1. if AG2(S.A.) then MC190(AG1), MC5, AG1 on hostile list, and MC0.
      2. if AG2(S.A.) and MC190(AG1) then MC45.
      3. if AG1(Israel) and AG2(ally) then EC2.
      4. if AGL(ally) and MC190(AG2) then mask MC190(AG2) and MC46.
      5. if AG1(Israel) and BC1 then mask BC1.
   B. Declarative-Negative
      1. if AG1(Israel) and EC2 then mask EC2 and EC27.
      2. if AG2(S.A.) and MC190(AG1) then mask MC190 and MC0, MC11, mask MC45, if MC200 and MC201 then mask MC200 and mask MC201 and MC100.

VI. Recognize
   A. Declarative-Positive
      1. if AG2(S.A.) then take AG1 off hostile list and if hostile list empty and MC0 then mask MC0.
      2. if AG2(S.A.) and MC60 then mask MC60.
      3. if AG1(I.) and AG2(P.L.O.) then BC1.
   B. Declarative-Negative
      1. if AG2(S.A.) then MC0 and AG1 on hostile list
      2. if AG2(S.A.) and AG1 Warsaw Pact state then MC60.
      3. if AG1(I.) and AG2(P.L.O.) if BC1 then mask BC1.

VII. Align (AG1 may be a collection)
   A. Declarative-Positive (political, military and security)
      1. if AG1(in Mid-East) and S.A. not in AG1 and U.S.A. not in AG1 then MC5.
      2. if S.A. in AG1 and western nation in AG1 then MC35.
      3. if S.A. and U.S.A. in AG1 then MC200 and if not MC190 and MC201 then mask MC201 and MC100 and mask MC200.
      4. if AG1(I.) then for x,x in AG1
         if EC4(x) then mask EC4(x) add EC5(x)
         if EC9(x) then mask EC9(x) add EC10(x)
         if EC12(x) then mask EC12(x) add EC13(x)
         if EC8(x) then mask EC8(x) add EC37(x)
         if EC14(x) then mask EC14(x) add EC15(x)
         if EC35(x) then mask EC35(x) add EC16(x)

5. if not EC17(x) and not EC5(x) and not EC10(x) and not EC15(x) and not EC16(x) and not EC36(x) and not EC37(x) then EC1(x).

B. Declarative-Negative (political, military, security)
1. if S.A. in AG1 and western power x in AG1
if x in treaty with S.A. take x off treaty list and if treaty list empty mask MC35.

C. Declarative-Positive (friendship)
1. if AG1(S.A.) and if friendship treaty with all mid-east nations signed then MC201 and if not MC190 and MC201 and MC200 then mask MC201, mask MC200 add MC100

D. Declarative-Negative (friendship)
1. if AG1(S.A.) for all x in AG1 other than S.A. take them off treaty list.

VIII. Rate kernels
A. if UNIT(oil) then enter in short term image as oil demand.
B. if UNIT(interest) then enter in short term image as interest rate.

IX. Level kernels
A. if UNIT(oil) then enter in short term image as price of oil.
B. if UNIT(fertilizer) then enter in short term image as price of fertilizer.
C. if UNIT(mechanization) then enter in short term image as price of mechanization.
D. if UNIT(wheat) then enter in short term image as price of wheat.

POLITICAL MILITARY SECTION

if M.S210 then OLD(**)
Printout = ===> is the U.S. willing to consider restoring support to Saudi Arabia?

If M.S165(AGNT) then OLD(**)
Printout = ===> Saudi Arabia will not buy arms from AGNT at this time.

If M.S95(AGNT) then OLD(**),M.C26(AGNT).
Printout = ===> Saudi Arabia will purchase arms from AGNT.

If M.S105 then OLD(**).
Printout = ===> In light of the current situation, Saudi Arabia asks for western support.

If M.S100 then OLD(**)
Printout = ===> Saudi Arabia calls on the peoples of the Arab world to unite.

If M.S110 then OLD(**)
Printout = ===> Saudi Arabia affirms its ties with the US and the west and asks for their support.

If M.S115 then OLD(**) and for each HOSTILE AGENT
Printout = ===> if AGNT is willing to cooperate with Saudi Arabia, we are willing to negotiate.

If M.S90 then OLD(**)
Printout = ===> is the US willing to provide arms to Saudi Arabia?

If M.S135 then OLD(**)
Printout = ===> is the USSR willing to provide arms to Saudi Arabia?

If M.S130 then OLD(**)
Printout = ===> are Britain, Sweden, or France willing to provide arms to Saudi Arabia

If M.S120 then OLD(**)
Printout = ===> Is the USSR willing to guarantee Saudi security?

If M.S170(AGNT) then OLD(**)
Printout = ===> Saudi Arabia attacks AGNT.

If M.S166(AGNT) then OLD(**)
Printout = Because of uncertainty with respect to revenues, AGNT is requested to approach US at a later time.

If M.S301(AGNT),(VALU) then OLD(**)
Printout = Because of severe budget constraints, Saudi Arabia must cancel arms contracts worth VALU with AGNT.

If M.C302(AGNT),(VALU) then OLD(**)
Printout = Because of short-term budget problems, Saudi Arabia must delay for a year, contracts worth VALU with the AGNT

If M.C25, not (M.C115) then OLD(**) and M.C25 (to budget sti)

If M.C75(AGNT),not (M.C115) then OLD(**) and M.C75(AGNT) (to budget sti)

If M.C25,not (M.C115),M.C5,not (M.C26(US)) then OLD(**) and M.C25 (to budget sti)

If M.C25,M.C115 then OLD(**),M.S165(US).

If M.C25,not (M.C5),not (M.C10) then OLD(**),M.S165(US).

If M.C25,M.C100 then OLD(**),M.S165(US)

If M.C75(AGNT),M.C5, not (M.C115),not (M.C26(AGNT)),M.C70, then NTC(M.C75(AGNT)), OLD(**), NTC(M.C75(AGNT)) OLD(**), and M.C75(AGNT) (to budget sti)

If M.C75(AGNT),M.C5,not(M.C115),not(M.C26(AGNT)),M.C140 then NTC(M.C75(AGNT)), OLD(**), and M.C75(AGNT) (to budget sti)

If M.C75(AGNT),M.C115 then OLD(**),M.S165(AGNT)

If M.C75(AGNT),not (M.C5),not (M.C10) then OLD(**),M.S165(AGNT)

If M.C75(AGNT),M.C100 then OLD(**),M.S165(AGNT)

If M.C75(AGNT),M.C25 then OLD(**),M.S165(AGNT)

If *M.C80*,M.C5,*M.C10*, *not*(M.C115),*M.C85(AGNT)*,*M.C45*,*not*(*M.C26(AGNT)*),M.C140 then NTC(M.C85(AGNT)),OLD(**) then M.C85(AGNT) (to budget sti) current sti = milit. sti

If M.C85(AGNT),M.C11 then OLD(**),M.S165(AGNT).

If M.C85(AGNT),M.C115 then OLD(**),M.S165(AGNT)

IF M.C85(AGNT),M.C46 then OLD(**),M.S165(AGNT)

If M.C85(AGNT),M.C100 then OLD(**),M.S165(AGNT)

If M.C85(AGNT),M.C75(STR) then OLD(**),M.S165(AGNT)

If M.C0,M.C5,M.C10,not(M.C35),M.C115 then EXIT,M.S100,M.S105

If M.C0,M.C5,M.C10,M.C115,M.C35,not(EXIT) then EXIT1,M.S100,M.S110

If M.C45,M.C140,not(EXIT2) then M.S115,EXIT2.

If M.C135,not(M.C180) then M.S105,M.S100,M.C180

If NOT(EXIT8),M.C110,not(M.C115),not(EXIT3),not(M.C190(US)) then OLD(**),M.S90,EXIT8

If M.C95,M.C5,not(M.C35),not(EXIT4) then EXIT4,M.S100,M.S105

If M.C95,M.C5,M.C35,not(EXIT5) then EXIT5,M.S100,M.S110

If M.C175,M.C90,not(EXIT6) then EXIT6,M.S100,M.S105

If M.S85(AGNT),M.C175 then OLD(**),M.S165(AGNT)

If M.C170,M.C80,not(M.C175) then M.C175,M.S135

If M.C75(AGNT),M.C170 then OLD(**),M.C75(AGNT) (to budget sti)

If M.C125,M.C70,not(EXIT$) then EXIT$,M.C170,M.S130

If M.C25,M.C125,not(EXIT7),not(M.C26(US)) then OLD(**),EXIT7,M.C25 (to budget sti)

If M.C0, M.C5,M.C10,not(M.C115),not(M.C125),not(EXIT8),not(M.C190(US)),not(EXIT3) then M.S90,M.C125,EXIT8.

If M.C190(STR.AGNT),not(EXIT9) then EXIT9,M.S170(AGNT)

IF M.C70,not(M.C140) then OLD(**),M.S210,M.C210

If M.C140,M.C110,not(OLD(M.S210)) then M.S210,M.C210

If M.C290 then OLD(**),M.S95(US)

If M.C295 then OLD(**),M.S166(US)

If M.C291(STR.AGNT) then OLD(**),M.S95(AGNT)

If M.C296(AGNT) then OLD(**),M.S166(AGNT)

If M.C292(AGNT) then OLD(**),M.S95(AGNT)

If M.C95(X) then if X is less than or equal to purchases from Warsaw states, then Warsaw purchases are reduced by X and M.S302((Warsaw)$); otherwise Warsaw purchases are set to zero and M.S302((Warsaw)$). The remaining funds to be cut are equally divided between Western Europe and the U.S. If purchases from the U.S. are greater than or equal to amount to be cut, then U.S. purchases are reduced by that amount and M.S302((US)$); otherwise U.S. purchases are reduced to zero and M.S302((US)$). If purchases from Western Europe are greater than the amount to be cut, Western Europe purchases are reduced by that amount and M.S((West Europe)$); otherwise Western Europe purchases are set to zero and M.S302((West Europe)$).

If M.C96, than repeat the above procedure, substituting M.S301((AGENT($) for M.S302((AGENT)$) throughout.

ECONOMIC SECTION

If E.S1(AGNT) then OLD(**)
Printout = Unless AGNT withdraws support from Israel, Saudi Arabia will deny foreign aid to AGNT.

If E.S2(AGNT) then OLD(**)
Printout = Because AGNT has continued to support Israeli aggression in spite of our warnings, all aid has been halted.

If E.S3(AGNT) then OLD(**)
Printout = As a result of AGNT's action, Saudi Arabia will restore suspended aid.

If E.S4(AGNT) then OLD(**)
Printout = Unless AGNT's support of Israel stops immediately, Saudi Arabia will restrict credit terms for oil purchases.

If E.S5(AGNT) then OLD(**)
Printout = As a result of continued support of Israel, AGNT must now pay cash for oil.

If E.S6(AGNT) then OLD(**)
Printout = Oil supply to AGNT will be halved in face of continued support for Israel.

If E.S7(AGNT) then OLD(**)
Printout = The supply of oil to AGNT has been halved.

If E.S8(AGNT) then OLD(**)
Printout = If AGNT continues to ignore repeated Saudi warnings, all oil will be cut off.

If E.S9(AGNT) then OLD(**)
Printout = No Saudi oil will be shipped to AGNT

If E.S10(AGNT) then OLD(**)
Printout = Saudi aid to AGNT will be halted unless AGNT renounces Israel.

If E.S11(AGNT) then OLD(**)
Printout = Saudi Arabia objects to AGNT's unfriendly actions, and will withdraw its investments if the situation is not rectified.

If E.S121(AGNT,AGNT) then OLD(**)
Printout = SA transfers all available capital from AGNT to AGNT2 in response to the hostility of AGNT.

If E.S13(AGNT) then OLD(**)
Printout = Saudi Arabia lifts the embargo against AGNT.

If E.S14 then OLD(**)
Printout = Saudi Arabia lifts all oil related restrictions.

If E.C1(AGNT),E.C2,E.C3(AGNT) then OLD(**),E.S1(AGNT),E.C4(AGNT)

If E.C5(AGNT),E.C2,E.C4(AGNT) then OLD(**),E.S2(AGNT),E.C7(AGNT)

If E.C4(AGNT),E.C2,E.C18(AGNT) then OLD(**)

If E.C7(AGNT),E.C18(AGNT) then OLD(**),E.S3(AGNT),E.C3(AGNT)

If E.C1(AGNT),E.C2,not(E.C3(AGNT)) then OLD(**),E.S4(AGNT),E.C8(AGNT)

If E.C37(AGNT),E.C2 then OLD(**),E.C9(AGNT),E.S5(AGNT) and
if not(TEMP.FLUX) then TEMP.FLUX(to budget sti)

If E.C10(AGNT),E.C2 then OLD(**),E.C12(AGNT),E.S6(AGNT)

If E.C13(AGNT),E.C2 then OLD(**),E.S7(AGNT),E.C14(AGNT) and
if not(TEMP.FLUX) then TEMP.FLUX(to budget sti)

If E.C15(STR.AGNT),E.C2 then OLD(**),E.S8(AGNT),E.C35(AGNT)

If E.C16(AGNT),E.C2 then OLD(**),E.S9(AGNT),E.C17(AGNT), and
if not(TEMP.FLUX) then TEMP.FLUX(to budget sti)

If E.C3(AGNT),E.C2,not(E.C18(AGNT)) then E.C3(AGNT),E.S10(AGNT)

If E.C4(AGNT),E.C2,E.C18(AGNT) then OLD(**),E.C3(AGNT),E.S3(AGNT)

If E.C17(AGNT),E.C30 then OLD(**),E.S13(AGNT)

If E.C17(AGNT),E.C18(AGNT) then OLD(**),E.S13(AGNT), and
if not(TEMP.FLUX) then TEMP.FLUX(to budget sti)

If E.C17(AGNT),E.C27 then OLD(**),E.S13(AGNT)

If E.C27 then OLD(**),E.S14, and if TEMP.FLUX (in budget sti) then OLD(**)

OIL SECTION

il 2 = if this month's L.PC has not replaced last month's L.PC then do so.

and

if the production capacity is less than the PC of two months ago then DPIR is equal to L.PC of last month minus PC (production capacity).

Oil 3 = if haven't checked to see if current proven reserves will last 15 years at current production then do so.

and

if reserves will not last 15 years then decrease production os that reserves will last 15 years. Put PSTOP in short term image.

Oil 4 = check to see if current production is equal to demand. If PSTOP is in short term image then do not modify production, otherwise modify balance production with demand.

Oil 5 = if not rev.ck then update budget projection. (current receipt and monthly production times months in fiscal year)

Oil 6 = if not one.ck then, if PAPC greater than 1.0 then PAPC = 1.0 and DPIR is set so that current demand will be met in 3 months.

Oil 6.3 = if not excess ck. and if current capacity exceeds demand by 60 percent then DPIR = 0.

AGRICULTURE SECTION

unnumbered production:

if cost of importing enough wheat to meet demands is more than 10 percent of fiscal year revenues then increase production of wheat (i.e., increase production into short term image). Note demand for wheat from Human Resources.

AG.1 = if YMECH = YFERT then recompute FERT and MECH by:
MECH = GVPMECH*((1.3*IRRW)-(.093*ATP))
FERT = GVPFERT* .046*IRRW

AG.2 = if YMECH > YFERT then recompute FERT by:
FERT = GVPFERT*.046*IRRW

AG.3 = if YFERT > YMECH then recompute MECH by:
MECH = GVPMECH*((1.3*IRRW)-1.093*ATP))

AG.5 = if INC.PROD in short term image
set IRRG to 20,000,000 o/w
set IRRG to 5,000,000

AG.6 = if cut(#) then if not INC.PROD then
IRRG=IRRG-cut(#)

AG.7 = if not o.k. then agriculture budget is
IRGG+FERT+MECH

AG. 7.1 = if IRGG = 0 then ag.final in short term image.

HUMAN RESOURCES SECTION

I. DEFINITIONS
   A. Control Statements Passed to Human Resources
      1. educal = persons in primary education system
      2. selfag = persons self employed in agriculture
      3. petrol = persons earning wages in petroleum industry
      4. milit 1 = persons serving as enlisted soldiers
      5. milit 2 = persons serving as officers
      6. civil = persons who are civil servants

HR2
if self-ag is less than 90 percent last year's self-ag then HR.C5(YEAR)

HR3
if pet is less than 90 percent last year's pet then HR.C4(YEAR)

HRM4
If HR.C5(YEAR),HR.C5(YEAR-1),not(HR.C2(YEAR))then HR.C2(YEAR)

HRM5
If HR.C4(YEAR),HR.C4(YEAR-1),not(HR.C2(YEAR))thenHR.C2(YEAR)

HRM6
If HR.C1(YEAR),HR.C1(YEAR-1),not(HR.C2(YEAR))thenHR.C2(YEAR)

HRM7
If HR.C2(YEAR),HR.C2(YEAR-1),HR.C2(YEAR-2),not(HR.C3(YEAR))then HR.C3(YEAR)

HRM8
If HR.C5(YEAR),not(HR.S4)thenHR.S4

HRM9
If HR.C4(YEAR),not(HR.S3)then HR.S3

HRM10
If HR.C3(YEAR),not(HR.S6)then HR.S6

HRM11
If HR.C2(YEAR),not(HR.S5)then HR.S5

HRM12
If HR.C1(YEAR),not(HR.S2)then HR.S2

HRM13
If HR.S2 then OLD(**),MILIT 1 = 0.0004,MILIT2 = 0.0048

HRM14
If HR.S3 then OLD(**),PETROL = 0.000171

HRM15
If HR.S4 then OLD(**),SELFAG = 0.0002

HRM16
If HR.S5 then OLD(**),CIVIL = 0.005

HRM17
If HR.S6 then OLD(**),EDUCA1 = 0.002

HRM18
If MILIT(SIR) then OLD(**),VALI = MILIT1*HR.A1 + MILIT2*HR.A4 * 21000
MILIT(VAL1)

HR19
if cut(#) then if cut is greater than expand(#) then expand (o). o/w divide cut equally between civil educa 1.

HR21
if not o.k. then HR budget equal to expand(#) + maintain(#) + milit(#). put HR(#) in budget module. And if expand(o) then put HR final in budget module.

BUDGET SECTION

BME1 = if B.PROJ + last year's revenue balance is < last year's revenue then MC115.

BME1.1 = if B.PROJ + last year's revenue balance is > last year's revenue and MC115 then mask MC115.

BME2.0 = if MC25 and if B.PROJ + last year's revenue balance is > last year's revenue then MC290.

BME2.1 = if MC25 and if B.PROJ + last year's revenue balance is < last year's revenue then MC295.

BME3.0 = if MC75 and if B.PROJ + last year's revenue balance is > last year's revenue MC291.

BME3.1 = if MC75 and if B.PROJ + last year's revenue balance is < last year's revenue MC296.

BME4.0 = if MC85 and if B.PROJ + last year's revenue balance > last year's revenue MC292.

BME4.1 = if MC85 and if B.PROJ + last year's revenue balance is < last year's revenue MC297.

BME5.0 = if month = BUD.TIME then go to BM otherwise read an input sentence.

BM1.0 = if not BC1 then Group1 = MIL.BUD + FOREIGN AID BUD. and Group2 = Human Resources Budget + Development and miscellaneous budget + Agriculture Budget.

BM2.0 = if 3C2 then Group1 = Human Resources + Development and Miscellaneous + Agriculture and Group2 = Military and Foreign Aid.

BM3.0 = if not BC2 then Group2 = Military and Group1 Human Resources, Foreign Aid, Development, Agriculture, Miscellaneous.

BM7.0 = if not BC9 and if Group1 + Group2 is > revenues then BC6
and if Group1 > revenues BC7
and if Group1 ≤ revenues BC8

BM7.1 = if not BC9 and if Group1 + Group2 ≤ revenues then BC4

BM8.0 = if B.REPORT printout budget.

BM9.0 = if BC4 and not BC1 then B.REPORT and 10 percent surplus revenues into long term investment and 90 percent in short term investment.

BM10.0 = if BC4 and not BC2 then B.REPORT and 40 percent surplus revenues into long term investment and 60 percent in short term investment.

BM11.0 = if BC4 and BC2 then B.REPORT and 10 percent surplus revenues into long term investment and 90 percent in short term investment.

BM16.0 = if BC7 then program error, run terminates program interrupt at . . .

BM17.0 = if BC8 and not BC1 and not BC9 and AG.FINAL, HR.FINAL, and DM.FINAL then BC9.

BM17.1 = if BC8 and not BC1 and not BC9 and not AG.FINAL, not HR.FINAL, or not BM.final then decrease non-final budgets to balance total budget.

BM18. = if BC8, BC2, not BC9, and MIL.FINAL, and FA.FINAL then BC9.

BM18.1 = if BC8, BC2, not BC9, and not MIL.FINAL or not FA.FINAL then decrease non-final budget to balance total budget. (IF TEMP.FLUX then MC96 otherwise MC95).

BM19.0 = if BC8, not BC2, and not BC9 and MIL.FINAL then BC9.

BM19.1 = if BC8, not BC2, and not BC9 and TEMP.FLUX then MC96.

BM19.2 = if BC8, not BC2, and not BC9 and not TEMP.FLUX then MC95.

BM20.0 = BC9 then reduce short and long term investments to cover deficit and B.REPORT.

DEVELOPMENT AND MISCELLANEOUS SECTION

The budget is initially set to $7,000,000,000 and lowest possible budget is $100,000,000. Otherwise all budget cuts by fiscal module are accepted.

FOREIGN AID SECTION

The foreign aid budget is initialized at $10,000,000 and lowest value is $1,000,000. Otherwise all fiscal module cuts are accepted.

The Project for Theoretical Politics
Simulation User's Manual

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1. EXECUTING THE PTP SIMULATION

The following steps are required to execute the PTP simulation:

1. You must be logged on ts0032. To logon ts0032 type:

   logon ts0032/XXXXXX id(XXXXXXXXXX) f(ad23) p(ptpuser)

2. Enter: ex system(ptpinit)

   This entry will initialize the simulation data files to the 1974 values.

3. Enter: sub system(spitcom)

   This entry will submit the simulation as a batch job.

4. Enter: ptpcom

   This entry will allow you to establish communication with the batch job. You have ten minutes from the time the submitted job begins executing to enter this instruction. The batch job is execution class B, so if there is a large B queue, the delay may be considerable.

PTPCOM will notify you when communication has been established. The first thing you should see after communication has been established is SPITBOL system output. After this has been displayed, the oil module will execute. After the oil module output has been displayed, the simulation will prompt for input by displaying the following: $$$ ENTER INPUT SENTENCE $$$. At that point there are two types of information that can be entered: control information and input sentences. The user should refer to section 2 concerning the valid grammatical constructs of input sentences before attempting any input of this nature to the simulation. In addition, the user should thoroughly examine section 3 describing control information that is either required or optional, to see what he must supply to the simulation as required input.

The aforementioned procedure for executing the simulation (logging on) is not unique. An alternate method for step 4 of the logon procedure will allow the "scenario" processing feature of the simulation to be executed. Processing of this nature is described in section 3 under the subsection on input scenarios.

In the event that the user feels he will require more than the "average" amount of processing time (approximately a two to five year run of the PTP simulation), an alternate method for step 3 of the logon procedure has been provided. To execute this procedure, step 3 of the previously given logon procedure should be modified so that the user will instead enter the following information:

sub system(spitcom2)

This essentially changes the batch processing Job Control Information which is given as input to the computer. This particular batch job is execution class C, and may require even more time than the class B job to get in the execution phase. This modification to the logon procedure provides more CPU time on the computer to the end user. Thus, this will increase the simulation run time, as well as the cost, greatly, and therefore should be used with much discretion.

In addition to the terminal printout generated by the simulation at a particular TSO terminal, hardcopy (paper output) will also be generated. Hardcopy output may be picked up at Baker Systems Engineering Building on the fifth floor. The user should refer to section 3 on Control Information for various methods of generating output (i.e., various features of output of the simulation may be suppressed or generated as desired by the user).

2. INPUT SENTENCES

There are two major classifications of input to the PTP simulation. Those are: control information and input sentences. This section will only describe those inputs of sentential form. The user should refer to section 3 for control information. Input sentences themselves are further classified into two major categories: agentive sentences and stative sentences.

2.1 Agentive Sentences

2.1.1 Verb Types

Agentive sentences express an action on the part of some agent or agents. There are two existing types of agentive sentences which are recognizable by the simulation: verb2 and verb3 sentences.

A verb2 sentence requires two elements other than the verb within the sentence, hence, its name (e.g., IS attacks SA). This example has an agent (IS), a verb (attacks), and a second agent (SA). Although a verb2 or verb3 sentence in which the subject agent is the same as the object agent is lexically valid, and will be parsed as such, it makes no sense contextually for an agent to perform an action upon itself, and it will therefore generate an error message to that effect (see section 5 on error messages). Some lexically valid examples of verb2 sentences may appear as follows:

US recognizes PLO.

IS will attack EGYPT.

IRAN will not raid SYRIA.

A verb3 sentence requires three elements other than the verb (e.g., US will not sell arms to SA). This sentence has an agent (US), a verb (will not sell; tense will be discussed later), a noun (arms), and another agent (SA). Since the simulation language follows the same basic constructs of the English

language, it is evident that verb3 phrases will require the use of a preposition. This is because sentences using verb3 verbs describe the action of some agent with reference to another agent. The required prepositions for this type of verb are found within the attribute list of verb3 verbs (see section 4) as follows:

BUY/V3/N(-ABSTRACT] + ABSTRACT) P(TO)/

The prepositions of the system: to, from, with; follow the corresponding verbs as they would in English. The following are lexically valid examples of verb3 agentive sentences:

US affirms security-treaty with IS.

Syria, Kuwait, Egypt sign peace-treaty.

France will give arms to Iran.

2.1.2 Sentence Tense and Forms

Due to the structure of the language recognizer of this simulation, the PTP language is a Context-Sensitive Language. Languages of this form are, by nature, restrictive in form. Therefore, for this simulated natural language to be parsed and interpreted correctly, the forms of the sentences given should be adhered to. As has been mentioned previously, the structure of the simulation language is very similar to English, although many of the special items such as articles (a, an, the), conjunctions (and, or), and adjectives have been omitted. Implementation of such features would have required more time and effort than was available and they were not essential to the operation of the PTP simulation. Since adjectives have been intentionally left out, the use of hyphenated words is provided to the user (see section 4 in the Table of Valid Lexical Entries). Although the input sentences may sound somewhat stilted to the user because of the lack of some English word-types, their meaning will be correctly interpreted by the simulation, provided they are listed correctly upon input into the simulation.

With respect to English grammar construction, various sentence types have been built into the simulation language. For verb2 and verb3 agentive sentences only, there are two verb tenses: present and future. In addition, the future tense may be either positive or negative (the latter is signified by the word 'not' in fron of the verb). In accordance with grammar, the endings of verbs change appropriately with tense, and, the word 'will' preceeding the selected verb is used to signify the future tense (Note: this is the only word which can be used to show future tense).

Another form of the agentive sentence is the interrogative sentence. The agentive interrogative sentence is not to be confused with stative interrogative sentence (described in subsection 2.2.4). The agentive question is meant to represent one country posing a question to another. It may not be used as a query to the system. An example of this would be:

WILL US GIVE ARMS TO IS?

Since this is not to be interpreted as a query to the system, the user should not expect an immediate response from the system. One restriction imposed is that the question be in the future tense (i.e., the word 'will' must be used). In addition, all questions must naturally end with a question mark. It should be noted, in accordance with the above description of agentive interrogative sentences, that in the above example, the simulation assumes that 'IS' is the speaker (i.e., Israel is asking the U.S.).

Using a simple verb3 sentence as an example, the following shows the four major sentential forms outlined above:

US sells arms to SA.

US will sell arms to SA.

US will not sell arms to SA.

Will SA buy arms from US?

The second sentence of the above example is not wholly correct and represents a special case within the simulation. With the verb3 verbs 'buy' and 'sell,' a special clause may appear at the end of the sentence. This is the "worth" clause, consisting of the word 'worth' followed by an integer dollar amount. Failure to enter an integer dollar amount may cause system failure. An example of this is:

US sells arms to IS worth $1,500,000.

It should be noted that when the verb 'sell' is used in the future - positive tense and the second agent is Saudi Arabia (i.e., the action is directed towards Saudi Arabia), it is mandatory to include a worth clause. This is to insure proper recording within Saudi Arabia's budget (primarily used with military transfers).

Another sentential form is provided in the simulation language by the use of "joint" verbs. There are only two verbs (verb3) within this class of verbs: sign, affirm. To model a multi-lateral action, multiple agents may be used with a joint verb (e.g., US, IS, SA sign security-treaty). Bilateral actions may be represented by single agents and the preposition 'with' (e.g., US affirms peace-treaty with IS) or, as a multi-lateral (e.g., US IS affirm peace-treaty). Although one can express a bilateral action as a multi-lateral action, a multi-lateral can not be represented in the same form as a bilateral (e.g., US, IS sign military-agreement with SA; this statement is incorrect).

2.2 Stative Sentences

2.2.1 Description

A stative sentence consists of a state description of the environment of Saudi Arabia. Stative sentences are, therefore, the means by which the user may change the simulation parameters (i.e., the perception of the simulation

concerning the affairs of Saudi Arabia. Note: these are not the Control Information to be mentioned in Section 3). If left unchanged by the user, these environmental parameters of the simulation will be set to default values (precomputed values based on 1974 statistics).

2.2.2 Types of Stative Sentences

There are two major types of stative sentences which can be interpreted by the simulation semantically: "level-types" and "rate-types." The first of these types may be described, generally, as prices or demands. The second type of stative sentence actually involves the setting of various rates (e.g., interest-rate, inflation-rate). Examples of the aforementioned stative sentences are given as follows:

Example Number	Stative Sentence
(1)	Oil price is $11.20 per barrel.
(2)	Wheat price is $72.20 per ton.
(3)	Fertilizer price is $.46 per ton.
(4)	Mechanization price is $120 per hp.
(5)	Oil demand is 7,700,000 barrels.
(6)	Interest-rate is 7%.

When assigning a price to a given noun, the price is assigned as per unit noun. The noun (e.g., oil, wheat, fertilizer) must first be a "value" noun before it may appear in an assignment statement of any nature. The simulation will parse the statement to check for this fact, and, if the assignment is a price stative assignment, it will check the stative sentence for valid <u>units</u>. Failure to enter the correct units for a given noun in this type of assignment (only required in a "price" assignment) will generate an error message to the user from the simulation (see section 5 on Error Messages). One can see from

the above examples that the price assigned must be followed by the word 'per' and the unit for that noun. Value nouns appear in the table of valid lexical entries as follows:

OIL/NOUN,VALUE,UNIT(BARRELS)/-ABSTRACT -COUNT/

In a price assignment, a dollar amount preceeded by a dollar sign must be present. Generally, the first five of the above examples are the only way to enter these particular assignments, with variation permitted in the price assigned, only. When an assigned value is large enough, commas may be inserted as desired since they will be ignored by the simulation (to be described below).

2.2.3 Interpretation of Stative Sentences

The meanings of the first four stative sentence examples should be reasonably self-explanatory. The fifth example, however, shows no unit such as 'per unit time' (as it is not required in "demand" assignments). This is because the unit of time is understood (by the simulation) to be the unit used here(i.e., it defaults to a unit of time and cannot be changed). The unit of time used for such "demand" stative sentences is assumed to be daily.

The user should be aware that the simulation is very sensitive to changes in oil demand as presented in an assignment statement. In addition, there is no conception of seasonal fluctuation in oil demand. For this reason, average demand should be used in these assignments. To accurately simulate oil demand, this average demand assigned should reflect average demand as mediated by OPEC's informal allocation rules. The rate of Saudi Arabia's oil production yielded by the simulation will change one month after the oil demand has been assigned a value, at which time a value (more or less) equal to the assigned demand will be produced. Care should be used in assigning a value to oil demand, in that, if the demand is set too low, it may not be enough to support the Saudi

system and may generate an appropriate error message. The same situation exists for price changes of oil (delay, etc.). The simulation simply accepts the price given from the stative sentence by the user and starts charging that amount. Thus, the <u>user is responsible</u> for accounting for OPEC changes. This responsibility is not assumed by the simulation.

The sixth example of stative sentence is a "rate-type" of sentence. For example, 'interest-rate' is meant to reflect the average interest paid to the Saudis on both its long and short term investments. Because of the lack of adjectives (mentioned before), the string 'interest-rate' must include the hyphen (the same is true for 'inflation-rate,' the only other "rate-type" noun which may be assigned a value from a stative input sentence). There are two equivalent variations permitted in entering the interest-rate (and inflation-rate):

e.g., Interest-rate is 7%.

Interest-rate is .07.

The unit of time assumed for these assignments ('interest'/'inflation') is 'per year' and may not be changed.

The stative sentences shown in the previous sections may be entered at any time during a run of the simulation. They may be readily interspersed with the aforementioned "agentive" sentences. Again, the user is cautioned to beware of the values he uses in these assignment statements. The examples which were shown before gave the actual default values taken on by the associated variables to which they were assigned, a fact the user might be able to incorporate into his own particular execution of the simulation. Also, these values may be used to give the user an idea of the type of value required for a given variable should he wish to change it. The user should also remember that there is a delay in response to some of the input stative sentences, but

that it (any changes made) should have to be put into effect by the time a month has been processed on the simulation. Again recall that unless these variables are changed (those shown in the examples), they will remain "in effect" throughout the execution of the simulation.

2.2.4 Stative Queries

Unlike the agentive question, the stative question is a direct query of the system. An immediate response should be expected by the user. The stative query is provided so that the user may inquire about the current values of stative variables (e.g., 'OIL PRICE,' 'INFLATION RATE'). It should be noted that only those variables which may be manipulated by the user can be queried. These variables consist of all the 'PRICE' information, 'OIL DEMAND', and 'INTEREST RATE.' An example of the stative query is as follows:

'WHAT IS OIL PRICE?'

Note that the article 'the' is not included because it is not recognized by the system. If the query cannot be handled, a message to this effect will be printed. Again, the question mark is required as an end symbol to this kind of query.

2.3 Sentence End Symbols and Delimiters

The grammar of the simulation can be viewed as a natural language, as was mentioned previously. By this analysis, there is an alphabet associated with the grammar permitted by the simulation. This alphabet consists of the twenty-six letters of the English alphabet, the ten arabic numerals, blank, hyphen, the special characters '$' and '%', commas, and valid sentence end symbols. Any characters other than the above will not be recognized by the simulation and will generate an 'unrecognizable word' message. The use of numeric quantities, hyphens, and the special characters '$' and '%', is given in subsections 2.1 and 2.2.

2.3.1 Positional Delimiters

A positional delimiter is defined here as those symbols which may be given by the user within input sentences to separate words or phrases. The symbols of this class are the blank and the comma. Both of these symbols may be written as frequently as desired by the user. However, like any higher level programming language, there must be rules to govern the use of these characters. Their allowable appearances within input sentences is described below.

Commas may appear absolutely anywhere in an input sentence. This is because the simulation grammar will completely ignore them. However, when parsing input sentences the grammar will replace all commas with null strings, an action which may produce erroneous results to the sentence. An example of this may be shown as follows:

Input Sentence:

US,IS SIGN FRIENDSHIP-TREATY.

Sentence After Commas Are Removed:

USIS SIGN FRIENDSHIP-TREATY.

The string 'USIS' will not be recognized by the simulation as a valid actor, and will produce a message to this effect. Therefore, each comma which delimits words must be followed or preceeded by at least one blank. The exception to this is shown in section 2.2, within stative sentence assignments. That is the case in which commas are used to keep track of positions within numeric strings (e.g., $7,700,000). In these cases, placing blanks before or after commas in numeric strings will yield unrecognizable numbers. Hence, blanks should be omitted surrounding commas in numeric strings.

Blanks, on the other hand, may only appear between words (here a numeric string or dollar amount string is considered a word). In addition, as many blanks as desired by the user may be put in input sentences, as long as at least one blank appears between two words.

2.3.2 Sentence End Symbols

Depending on the type of input being done, the input string may or may not require an end symbol. Both sentences and control information may be entered into the system. Control information does not require any end symbols. Input sentences, on the other hand, do require end symbols. The valid sentence end symbols are the period(.), the semi-colon(;), and the question mark(?). If a sentence is entered without any end symbol, an error message will be produced. NOTE: If parts of a sentence (i.e., object-agent, prepositional phrases if required, etc.) are missing, the simulation will trigger a 'missing end symbol' message here also.

Each of the sentence end symbols has a special significance. A period at the end of a given user input sentence will inform the simulation that "normal" processing of the sentence is to take place. This implies that the sentence is to be parsed by the simulation grammar, interpreted semantically, and run through the set of simulation productions.

A semi-colon used as an end symbol causes the sentence to be parsed and interpreted but not run through the simulation productions. With this end symbol, the user may simulate parallel actions taking place. That is, the interpreted meaning of all input sentences with semi-colons will be perceived by the system, but, the system will not proceed with any operation on these inputs until the next sentence with a period or a question mark is entered, at which time all of the interpreted sentences will effectively be operated on. Therefore, the semi-colon signals the simulation that batched input is to occur.

A question mark informs the simulation that the associated sentence is a question. Questions are described in detail in subsections 2.1.2 and 2.2.4. Since it is mandatory that each query must end with this end symbol, no

other end symbols may be used to replace it. Thus, batched input is not possible with queries.

2.4 Simulation Agents

The construction of agentive input sentences (described in subsection 2.1) requires that verb2 sentences have at least one agent, the principal "do-er" of the action given in the sentence, while verb3 sentences must have at least two agents, the principal "do-er" of the action and the "receiver" of the action. There are exceptions to these rules. Some verb2 sentences may have a second agent, the "receiver," while some verb3 sentences may have more than two agents (see subsection 2.1.2 concerning "joint" verbs). All of the agents mentioned above must come from the list of valid actors (agents) of the simulation. In addition, when writing these agents within input sentences, the user must be certain to use the correct character string representation of the agent's name (i.e., neither 'United States', 'Saudi Arabia', nor 'Soviet Union' will be recognized by the simulation). If a character string representation of an agent is used which is not in the table of valid simulation actors an 'UNRECOGNIZABLE WORD' message will be produced. The user should refer to section 4 (PERMITTED VOCABULARY) for the correct character string representation of the allowed agents within the simulation.

2.4.1 Execution Time Agents

When the simulation first begins execution, certain knowledge, which may be viewed as the "perception" of "state knowledge" of Saudi Arabia, it is initialized by the system. Some of this knowledge pertains to the relation of Saudi Arabia with the other agents of the system. The following categorical relationships are set up:

ALLIES (of Saudi Arabia): US, France, Britain, Sweden, Egypt, and Syria.

The following geographical relations are set up:

MIDEAST: Israel, Egypt, Syria, Iran, United Arab Emirates, Iraq, Kuwait, PLO.

WEST: US, France, Britain, Sweden

WARSAW: USSR

Note that not all of the simulation actors are used here (see section 4).

2.5 Default Simulation Values

It is most reasonable to assume that there are many variable parameters controlling the operation of the PTP simulation. Some of these parameters may be changed by the user (see subsection 2.2 concerning stative sentences). Other variables can be only changed by the simulation itself. Still another kind of these variables may not change during the course of the simulation at all. The following is a compiled list of some of those variables of the simulation and the initial values given to them by the simulation. The user should refer to subjection 2.2 under "Stative Sentences" in conjunction with section 4 (PERMITTED VOCABULARY) to see which of these parameters may be changed. These variables are as follows:

State Variable	User Controlled	Initial Value
Oil Demand	Yes	7,700,000 barrels/day
PAPC*	No	.8149
DPIR*	No	95,000 barrels/day
Oil Posted Price	Yes	$11.651 per barrel
Wheat Price	Yes	$72.20 per bushel
Fertilizer Price	Yes	$0.47 per ton

State Variable	User Controlled	Initial Value
Fertilizer Demand	No	15,000 tons
Mechanization Price	Yes	$120 per horsepower
Mechanization Demand	No	5,000 horsepower
Irrigation Allocation	No	$500,000
Long-Term Investments	No	$53,328,766.00
Short-Term Investments	No	$362,857,252.00
Foreign Aid Budget	No	$10,000,000
Military and Defense Budget	No	$7,000,000,000
Month	Yes (by EOM)	8
Year	Yes (by EOM)	1974
OPTIONS IN EFFECT**		'OILPRINT'

*Refer to Project for Theoretical Politics Working Papers #15, 23 for description.

**Refer to section 3 on Control Information (LISTOP command).

3. CONTROL INFORMATION

The execution of the simulation is dependent upon a batch processing link with time sharing. Thus, breaking this link will cause the simulation to cease operation. At the time when the user receives the 'COMMUNICATION HAS BEEN ESTABLISHED' message, the aforementioned link is built and the simulation enters the PTPCOM mode. This mode of operation is restricted to simulation operation only. That is, the user is no longer in control of any system time sharing features and cannot access them. He may, at this time, only enter input and receive output from the simulation. The user should be aware of this restricted operation.

3.1 Required Control Information

3.1.1 Ending the Simulation

To terminate the simulation, the user must enter the character string '/*' (without quotes). This method of termination may be used whenever the simulation prompts the user for input. Special cases exist when "scenarios" are being processed (to be described in a later section). The user may enter this even when he is not prompted, if it can be entered between output from the simulation, but this is generally not suggested. Entering symbols (or sentences) when not prompted for them by the simulation has the effect of "staggering" the input. Generally, if more than two lines of input are staggered at the terminal, the simulation will have an Abnormal Termination (ABEND).

The effect of entering '/*' (without quotes) is to break the batch-time sharing communications link, and, to return the user to normal time sharing processing. The user, at this time, may now use all of the time sharing features available to him at the beginning of the session. It should be noted that the communication link is not known to be broken until a 'READY' message is received at the terminal from the system. If, at any time during the execution of the simulation, this 'READY' message is received, the user should recognize that the link is broken, and, if desired, repeat the entire process of re-submitting the simulation as a batch job (refer to section 1). Since wait-time in the job queue is usually long, one can see why it is undesirable to have a restart the simulation in this manner.

3.1.2 Abnormal Job Termination (ABEND)

There are several things which may cause the simulation to ABEND. One of these situations, "staggering input", is described in subsection 3.1.1. Another cause for abnormal termination is the over-running of the time parameter (of the

SPITBOL decision module). If the user has entered the simulation by way of SPITCOM, and receives an ABEND, he may be attempting to process too many years of the simulation or he may be simply processing too long. This situation may be corrected by using SPITCOM2 as described in section 1.

An ABEND may also be caused by the SPITBOL decision module if too many statements are executed during a particular run of the simulation. The current allowed limit is 268,435,456 statements, and should be sufficient for normal processing. Note here that this statement limit refers only to the number of SPITBOL statements executed, not the number of input sentences passed to the simulation. Any error messages received from the SPITBOL decision module concerning the statement-limit should be reported to the authors. Pressing the attention key on the terminal will cause the PTPCOM mode to terminate, thus breaking the communication between the batch job and the time sharing terminal session. This will also cause the batch program to ABEND. Abnormal terminations of the previously described form should be avoided if at all possible. The user should note that if he has overrun the time parameter, the simulation may cease operation at any point. If this occurs in a sector module (PL/I), the data returned to the SPITBOL decision module would be erroneous, and, an error message would be printed such as '***ERROR***ILLEGAL DATATYPE'. STI errors may also occur if the time parameter is exceeded. Again, the solution here is to use the SPITCOM2 submittal method (refer to section 1) instead of SPITCOM. This is not actually an error in the simulation system. If the problem is not rectified, report the situation to the authors.

3.1.3 End of Month (EOM)

The character string 'eom' (entered without quotes) signals the simulation that the current month has ended. This symbol is necessary to simulate time

sequence actions within the simulation. The effect of this instruction is to increment the month by one, and execute the oil module. Note that the month will not increment without the entry of eom. The actions of some sentences require more than one month to be completed. Thus, the user should enter eom's to observe all of the results of given input.

To receive any output from the oil, agriculture, human resources, or budget modules, it is the user's responsibility to enter eom's. All of these modules, except for the oil module, process and print at the end of the Saudi fiscal year (the oil module prints monthly, see above). In order to simulate a Saudi fiscal year, 12 or 13 eom's must be entered. Because of the nature of the calendar used by the Saudis, the beginning of the fiscal year changes. Every fourth year is a thirteen month year. The simulation knows this and behaves accordingly. After the appropriate number of eom's have been entered, the simulation will initiate the execution of the agriculture, human resources, and budget modules, in addition to the output from the oil module for that month.

There is virtually no limit to the number of statements (input sentences) which may be entered between entering eom's. For accurate modeling, however, it is desirable to control the amount of user input at these times. It is not necessary to enter any other input eom's. This may be used to observe the time-wise production of Saudi Arabia with no interaction. However, it should be remembered that it is the user's responsibility to signal the end of a month to the simulation.

3.2 Optional Control Information

3.2.1 Short Term Image (STI) and Productions

All optional control information for the simulation mentioned in this section refers to output listing control of the decision module.* One of these

*For discussion of the decision module, see PTP Working Paper #13.

structures within the decision module, the short term image, whose printing is controlled by the parameter 'PRINT' (to be described later), should be described here for clarity to the user. The short term image is actually a SPITBOL data structure representing the memory of Saudi Arabia. A piece of state knowledge, existing in the character representation form of a production (e.g., 'M.C110'), resides as one element in the short term image. The simulation keeps track of the head of each STI, and, therefore has recollection about what is most recently learned or known by Saudi Arabia. The head of the STI is linked (in a list-like fashion) to each following element in the STI. Thus, the simulation is able to manipulate the entire STI, knowing which element is which. A listing of the STI would show several separate and distinct elements.

Productions are statements which test the contents of the STI or change the contents of the STI (Condition and Action, respectively). It is the changing of the STI which simulates the knowledge which is currently known by the Saudis. For the contents of the STI to make any sense, however, the user must have a list of various productions used by the simulation and their corresponding codes. The production systems are the means by which the decision module actually makes logical choices of action. In addition the SPITBOL decision module keeps track of the location of the productions being executed at a given time, and, the type (Condition (c), or Action (a)) of the production.

There are several STI in the simulation described as follows:

STI Name	Number of Elements	Type
DM.STI	5	Development or Misc.
AG.STI	15	Agriculture
HR.STI	15	Human Resources

STI Name	Number of Elements	Type
FA.STI	5	Foreign Aid
BUD.STI	20	Budget
MILIT.STI	25	Military and Defense
ECON.STI	25	Political/Economic

The user may not directly manipulate these STI, but, may observe the contents of them at any time during the execution of the simulation. Methods for doing this are described in the following sections (see 'PRINT').

3.2.2 Optional Simulation Control Inputs

Simulation control symbols, in the same manner as the required control inputs, may be entered as input to the simulation. These control statements may be entered any time the simulation prompts the user for input. The user should note that the spellings of the control statements must be correct for the simulation to interpret them correctly. In addition, these symbols must not be entered with any sentence end symbols. The actions (i.e., system responses), which these statements control, will come into effect immediately after entering them. The optional simulation control parameters are as follows (when entered they must not have quotes around them):

'PRINT'/'NOPRINT' - The 'PRINT' parameter to the simulation, if entered, will cause each change in the short term images (see subsection 3.2.1) to be displayed. This will generate output each time a production executes in which a reference to any STI is made. Each element of the current STI, at the time of the execution of a given production, will be printed according to its position within the STI. The production elements within the STI are in coded form and will make little sense to the user unless he has a listing of the simulation productions and their corresponding

codes. It is for this reason, and the fact that this option produces large amounts of output, that its use is suggested to be limited. This option may be "turned off" by its default value, the 'NOPRINT' parameter.

'ECHO'/'NOECHO' - The 'ECHO' command signals to the simulation that each input, following this command, is to be printed at the terminal <u>and on hardcopy</u>. It should be noted by the user that user input (including control information) will not appear on hardcopy if this parameter is not "turned off." After a run of the simulation, any hardcopy (paper output) from the simulation may be picked up on the fifth floor of the Baker Systems Engineering building under TS0032. The default value for this parameter is 'NOECHO'.

'KERNEL'/'NOKERNEL' - This parameter prints the semantic kernel (interpretation) of the current input sentence generated by the simulation grammar. For this parameter to be used effectively, the user must know the general form of the semantic kernel. A semantic kernel has the following form for the <u>agentive</u> input sentences:

Kernel-type(Agent1,(Agent2),(Object))/Tense,Sign/Dec[Int] (Agent1)/

Agent1, agent2, object of sentence, tense of sentence, and sign (positive or negative) are described in subsection 2.1. DEC refers to whether the sentence is <u>declarative</u>, and, INT refers to whether the sentence is <u>interrogative</u>. Note that only one of the pair [DEC,INT] will appear in the kernel. The agent of this clause is the primary agent of the sentence. The form of the semantic kernel for the stative sentence is as follows:

Kernel-type(Noun assigned the value,Value assigned)

The possible values for Kernel-type reflect the nature of the input sentence. These possible values within the realm of the simulation are as follows:

Values of Kernel-type	Sentence Type
'RATE'	Stative
'LEVEL'	Stative
'TRANSFER'	Agentive
'ALIGN'	Agentive
'SUPPORT'	Agentive
'FORCE-DISPLAY'	Agentive
'ATTACK'	Agentive
'RECOGNIZE'	Agentive

This parameter has a default value of 'NOKERNEL', and may be turned off by the same. This parameter may be of interest if the user desires to observe the internal workings of the simulation grammar.

'COND'/'NOCOND' - This parameter may be given by the user to print the conditions (c) and the actions (a) of any productions executed. In addition, the <u>location</u> of said condition or action is printed. This location is the location within the SPITBOL decision module source code. Once this keyword has been activated, the parameters of each 'TRUE' (satisfied) condition and the associated action statement parameters will be printed (see subsection 3.2.1 for description of productions). This parameter is in effect until it is turned off by the associated 'NOCOND' parameter. The possible production locations within the

decision module when the 'COND' parameter is "turned on" are given as follows:

<u>Section Within Decision Module</u>

Initialization

Interpretation

Military

Economic

Oil

Agriculture

Human Resources

Budget

Foreign Aid

Development and Miscellaneous

A sample output from the PTP simulation using this parameter may appear as follows (e.g., in this example it is given that the satisfied condition statement was in the 'INTERPRETATION' section of the decision module):

C -- INTERPRETATION == NOT(E.C37(US))

A -- INTERPRETATION == E.C1(US)

It should be noted again by the user that a knowledge of possible simulation productions as outlined in subjection 3.2.1 would be helpful here.

'OILPRINT'/'NOOILPRINT' - The 'OILPRINT' keyword permits the user to suppress the output from the PTP oil module, which currently prints on a monthly basis. All monthly output from this module (this does not apply to the hardcopy output - paper output, it is still generated, while the terminal printout is not) except that which occurs in the

last month of the Saudi year (month = 7, or, every 4th year, month = 8) will be suppressed. Like the other parameters, this option may be turned on or off at the desire of the user, but, as mentioned prior, the last month of the Saudi year will print automatically. It should be noted by the user that he will still receive the output of the end of month message and the output displaying the current month and year. This parameter will suppress a considerable amount of output from the simulation. The default value for this parameter is 'OILPRINT.'

'LISTOP' - The 'LISTOP' keyword may be used to print which of the previously mentioned optional simulation parameters are in effect at a given time. If they are in effect, the keyword name for a given parameter will be given (e.g., 'COND'), if not, the second negated form of the keyword for a given parameter is given (e.g., 'NOPRINT'). Thus one of the two values of each parameter pair (e.g., 'ECHO'/'NOECHO') will be printed by this command.

All of the simulation optional parameters are recanted in the following table along with their default simulation values. Note that these values will not change unless changed by the user. The optional parameters are again as follows:

Optional PTP Simulation Parameters

Keyword of Parameter Pair	Default Value
ECHO/NOECHO	NOECHO
KERNEL/NOKERNEL	NOKERNEL
COND/NOCOND	NOCOND
PRINT/NOPRINT	NOPRINT
OILPRINT/NOOILPRINT	OILPRINT
LISTOP	[does not apply]

3.3 Scenario Processing

3.3.1 Definition

A scenario is a preplanned organization of input sentences prescribed by the user to model a predetermined set of events. A scenario may consist of any of the allowed user inputs of normal processing (see section 2, subsections 3.1, 3.2). Within the bounds of the PTP simulation, a scenario may only exist as a member dataset of a "partitioned dataset." Users should refer to other computer manuals for a definition of partitioned datasets. In addition to this requirement, all scenarios which are to be processed within one run of the simulation must be members of the same partitioned dataset. That is, the user may only specify one partitioned dataset as the "scenario library" for a given run, and, the system automatically searches this library for the given scenarios requested. Other scenarios libraries (other partitioned datasets) may of course be kept, but will not be searched by the PTP simulation.

3.3.2 Specifying Scenario Libraries

For the user to inform the simulation that scenarios will be read during execution, the user must enter the execution mode PTPCOM. This mode is entered as follows:

ptpcom-mode lib(fully qualified partitioned dataset name)

where:

ptpcom-mode is: PTPCOM

lib(XXXXXX) is: the scenario library name to be searched.

An example of this is as follows:

ptpcom2 lib(ts0538.lib.data)

It is not necessary to specify the fully qualified name if the user is logged on TS0032. Nor is there any big difference in using TTY compatible characters of lower case characters. In the example above, the simulation would note

that 'TS0538.LIB.DATA' is the scenario library and would search there for specific scenarios requested during the course of the simulation. Other user requirements for scenario processing exist only after execution has begun and are listed below.

3.3.3 Specifying Scenario Members

As is mentioned in subsection 3.3.1, an individual scenario exists as a member dataset of the scenario library dataset. Providing that the correct execution modes were specified, the user may request the processing of individual scenarios any time after he is first prompted for input by the simulation (i.e., $$$ ENTER INPUT SENTENCE $$$). Thus, once execution has begun, a user may input a scenario request in place of an input sentence, at any time. This request must appear as follows:

=member name

where 'member-name' is the partitioned dataset member of the library which is scenario desired. For example, if a scenario library, TS0538.LIB.DATA, contained three scenarios as member datasets, CRISIS, IG238, WEATHER; the user could request them in this fashion:

$$$ ENTER INPUT SENTENCE $$$	(simulation input prompt)
.	
=CRISIS .	(user response)
.	
=IG238 .	"
.	
=WEATHER .	"

The scenarios will begin processing immediately after the reference has been made. In PTPCOM2 and PTPCOM3 this processing cannot be halted until all of the sentences in the scenario have been read and the simulation prompts the user for input. It should be noted that the simulation will print out the user prompt after each scenario sentence but will immediately read the next scenario sentence onto the input stack. Thus, the user should wait until

he is certain that the last sentence has been read before further entering any input. The execution mode PTPCOM4 allows the interrupting of scenarios (see below), but, if the interrupt key is hit in PTPCOM2 or PTPCOM3 (or PTPCOM), the simulation will most likely terminate or a terminal "lockout" condition may occur.

In addition to making scenario requests as user input, the user may place such a request directly in a scenario (as one of the input sentences). This can be done in such a way as to build a large scenario out of several existing smaller ones. However, the user should confirm the existence of his scenario datasets before attempting to reference them within the simulation, since, once the simulation has started, it is not possible to "list" the contents of a dataset. The user should also take care not to devise a circular reference which would result in an infinite loop. This may be seen in the following example:

=IG1	(within member IG2)
=IG2	(within member IG1)

The system is not equipped to recognize such a condition and it will clearly result in much grief if it is permitted by the user to exist in his scenarios.

It is suggested that the first statement in user scenarios is 'ECHO' (see subsection 3.2.2). Otherwise, the sentences coming from the scenario will not be displayed at the terminal or on hardcopy. Thus, if the user does not know his scenario, verbatim, he will not know of its contents (other than output sentences generated by the simulation) without this command. These scenarios may also contain any other valid input sentences including control information and scenario references and may therefore represent a wide variety of modeling. Since the scenarios require no user intervention during

their execution, the processing time is greatly optimized as well as the throughput volume of the simulation. This processing method is then suggested as a viable alternative, in lengthy simulation sessions, to continuous user input.

3.3.4 PTPCOM, Interrupt-handling Execution Mode

Using PTPCOM enables the user to interrupt the execution of the scenario during its processing. It should be noted that input from the scenario is placed on a stack once it is read from the dataset but before processing. Thus, to interrupt the scenario, the user must press the attention key <u>once</u> and wait until the rest of the stack has completed processing. This may take some time, but will readily be recognized as the simulation will print a message:

ATTN INTERRUPT ==])

Pressing the attention key repeatedly (rapidly) may result in control being returned to the terminal monitor program (i.e., a READY message). It should be noted also that this attention exit is not available until the batch/time-sharing interface link is built (see first paragraph of major section 3).

The user may also build the attention into a scenario by placing the string '=*' (without quotes) as an input sentence in a scenario. This will cause a simulated attention interrupt. The user may then enter the optional interrupt commands (as with regular interrupts) as described below. It should also be noted here that these are not legitimate terminal commands but, rather, special PTP system commands which are designed for use on the PTP simulation and are only valid in such a system environment.

Once an attention interrupt has been acknowledged (attention message printed), the user may do one of the following:

a.) Send statements directly to the simulation.

b.) Delete the rest of the scenario (see below).

c.) Resume the scenario (press carriage return).

d.) Terminate PTPCOM -mode (enter '/*', without quotes)

e.) Send a new scenario and then resume the old scenario (enter: =new-member)

The string '=/*' (without quotes) may be used to delete the scenario stack once an interrupt has been acknowledged. The user may then enter input sentences as normal. This string may also appear directly in a scenario, although there is no apparent reason to do so. There is a great deal of flexibility associated with scenario processing, and, if used effectively, it could be an imaginative modeling tool.

4. PERMITTED VOCABULARY

The following section lists all of the permitted vocabulary of the PTP simulation. Words, such as 'WILL' (used in questions and to designate verb tense) and 'IS' (verb form used in noun value assignments, not Israel), are not shown. All words may be entered in the same manner as shown (words are shown before the first slash of each lexical entry) with some exceptions. The verbs with asterisks ('SIGN', 'AFFIRM') should be entered without asterisks and are the regular forms of said verbs, as opposed to the other form, the "joint" form (described in subsection 2.1.2). This non-joint form requires the use of the preposition 'WITH'. Other exceptions are two actors ('UAE-INSURGENTS', 'KUWAIT-INSURGENTS') which appear as plural forms but should be regarded as singular. Thus, like other actors, these require verbs in the first person singular form, although such a form will sound odd (e.g., 'UAE-INSURGENTS RAIDS SA').

4.1 Attribute Groups

Each noun entry is listed with specific simulation attribute groups. Each verb entry is listed with the verb type, the attributes of associated nouns, and required prepositions (only in 'verb3' type verbs). In addition to nouns and verbs, actors and prepositions are listed (which have no attributes). The user can then design lexically valid sentences by matching verb and noun attributes.

The first set of noun attributes (which appear between first and second slash) describe the wordtype ('NOUN'), whether it may be used to assign a 'WORTH' clause ('WORTH'; see subsection 2.1.2), whether it may be assigned a value ('VALUE'; see subsection 2.2.2), and if used in a value assignment, what type of units (e.g., 'PER TON') must be specified ('UNIT(. . .unit. . .)'). The second set of noun attributes (appearing between the second third slash) reflects the nature of the noun in question, such as whether it is an abstract noun (e.g., 'MILITARY-AID') signified by '+ABSTRACT', or non-abstract signified by '-ABSTRACT', and whether the noun can be given in countable units ('+COUNT') or not ('-COUNT'). Some of these attributes are optional, which can be readily seen, but, the last two of these attributes mentioned will usually appear.

Verb attributes are somewhat more simple. First, the type of the verb, as described in subsection 2.1.1, is listed. This section is followed by a general attributes section (between the second and third slash). The attributes of nouns which may be used as objects of these verbs are listed (e.g., 'N(. . .attributes. . .)'). These attributes must be present in the noun entries. An error message will be produced for verb and noun attributes which do not match (within a given input sentence). Also, the noun attributes

of the object of a 'verb2' verb are only that the noun be an actor (see subsection 2.1.1). In the case of 'verb3' verbs, a preposition is required between the object of the sentence and the second actor, and, is listed in the second attribute section (e.g., 'P(. . .required preposition. . .)').

Other words ('DEMAND', 'RATE', 'PRICE') may only be used in value assignments and therefore have no attributes (see subsection 2.2.2). Any word that is given in an input sentence and is not either assumed by the simulation (described above) or appearing in the table of permitted vocabulary, is marked as an unrecognizable word by the simulation grammar.

With the grammatical structure of the PTP simulation, some of the inputs may sound rather strange. In actuality, they are not exactly like the English language, but are rather close copies. Again, the structure of a 'natural' language would be too ambiguous for use on the computer. Thus a language more closely representing a compiler-type language was created. The structure of sentences, in accordance with standard English grammar, requires that the endings of verbs should change, depending upon the tense of the input sentence. This and other requirements is the attempted simulation of the English language.

4.2 <u>Valid Lexical Entries (NOUNS)</u>

ARMED-FORCED/NOUN/-COUNT +ANIMATE/

ARMS/NOUN,WORTH/-ABSTRACT -COUNT/

ARMS-RESUPPLY/NOUN,WORTH/-ABSTRACT -COUNT/

ASSETS/NOUN,WORTH/-ABSTRACT -COUNT/

CAPITAL-GOODS/NOUN,WORTH/-ABSTRACT -COUNT/

COMTUP/NOUN,WORTH/-ABSTRACT -COUNT/

CONSUMER-GOODS/NOUN,WORTH/-ABSTRACT -COUNT/

DEMAND/NUMBER,TIME(DAY,MONTH,YEAR)/NOUNTYPE/

ECONOMIC-AID/NOUN/+ABSTRACT -COUNT/

FERTILIZER/NOUN,VALUE,UNIT(TONS)/-ABSTRACT -COUNT/

FRIENDSHIP-TREATY/NOUN/+ABSTRACT +COUNT/

INFLATION/NOUN,VALUE,UNIT(YEAR)/+ABSTRACT -COUNT/

INTEREST/NOUN,VALUE,UNIT(MONTH,YEAR,QUARTER)/+ABSTRACT -COUNT/

MECHANIZATION/NOUN,VALUE,UNIT(HP)/-ABSTRACT -COUNT/

MILITARY-AGREEMENT/NOUN/+ABSTRACT +COUNT/

MILITARY-AID/NOUN/+ABSTRACT -COUNT/

MILITARY-SUPPORT/NOUN/+ABSTRACT -COUNT/

OIL/NOUN,VALUE,UNIT(BARRELS)/-ABSTRACT -COUNT/

POLITICAL-AGREEMENT/NOUN/+ABSTRACT +COUNT/

POLITICAL-SUPPORT/NOUN/+ABSTRACT -COUNT/

PRICE/PRICE/NOUNTYPE/

RATE/PERCENT/NOUNTYPE/

SECURITY-TREATY/NOUN/+ABSTRACT +COUNT/

TNC/NOUN,WORTH/-ABSTRACT -COUNT/

WHEAT/NOUN,VALUE,UNIT(TONS)/-ABSTRACT -COUNT/

4.3 Valid Lexical Entries (VERBS and PREPOSITIONS)

AFFIRM/V2/JOINT N(+ABSTRACT +COUNT)/

AFFIRM*/V3/N(+ABSTRACT +COUNT) P(WITH)/

AGAINST/PREP/NONE/

ALERT/V3/N(+ANIMATE) P(AGAINST)/

ATTACK/V2/N(ACTOR)/

BUY/V3/N(-ABSTRACT) P(FROM)/

DISRUPT/V2/N(ACTOR)/

FROM/PREP/NONE/

GIVE/V3/N(+ABSTRACT -COUNT | -ABSTRACT) P(TO)/

IMPOUNT/V3/N(-ABSTRACT -COUNT) P(OF)/

MOBILIZE/V3/N(+ANIMATE) P(AGAINST)/

PURCHASE/V3/N(-ABSTRACT) P(FROM)/

PROVIDE/V3/N(-ABSTRACT | +ABSTRACT) P(TO)/

RAID/V2/N(ACTOR)/

RECOGNIZE/V2/N(ACTOR)/

SEIZE/V3/N(-ABSTRACT -COUNT) P(OF)/

SELL/V3/N(-ABSTRACT) P(TO)/

SIGN/V2/JOINT N(+ABSTRACT +COUNT)/

SIGN*/V3/N(+ABSTRACT +COUNT) P(WITH)/

TO/PREP/NONE/

WITH/PREP/NONE/

4.4 <u>Valid Lexical Entries (ACTORS)</u>

SA	(Saudi Arabia)
US	(United States)
IS	(Israel)
USSR	(Russia)
BRITAIN	
EGYPT	
FRANCE	
SWEDEN	
GERMANY	
SYRIA	
IRAN	
KUWAIT	

UAE (United Arab Emirates)

PLO

IRAQ

UAE-INSURGENTS

KUWAIT-INSURGENTS

5. ERROR MESSAGES FOR THE PTP SIMULATION

Messages Generated by Grammar

mssg. '***ERROR***' word 'IS NOT A VALUE NOUN'

descr. The given word is not one of those which can be used in making an assignment. Words which may be assigned values appear as follows in the table of valid lexical entries: e.g., OIL/NOUN,VALUE,...

mssg. '***ERROR***' word 'IS NOT A VALID QUALIFIER'

descr. The given word is not one of those valid qualifiers which may be used in assignment statements following the primary noun (oil,fertilizer,etc.). Valid qualifiers are: price, rate, demand.

mssg. '***ERROR*** SENTENCE DOES NOT HAVE A VALID END SYMBOL'

descr. This message is generated if the input sentence does not end in one of the valid end symbols ('.' or ';' or '?'). It may also occur if a partial sentence is entered, or, if more sentence parts were expected (prepositional phrase missing, etc.)

mssg. '***ERROR*** WRONG UNITS SPECIFIED FOR THIS NOUN'

descr. Incorrect units were used in an assignment statement. Correct units appear in the table of VALID LEXICAL ENTRIES (see section 4) in the following manner: e.g., OIL/NOUN,VALUE,UNIT(BARRELS)/...

mssg. '***ERROR*** A JOINT VERB REQUIRES 2 ACTORS'

descr. When using this multilateral form of a joint verb, 2 or more actors were not entered simultaneously as the subject of the sentence.

mssg. '***ERROR*** NON-MATCHING VERB/NOUN ATTRIBUTES'

descr. The attributes of the verb and noun as given in the table of VALID LEXICAL ENTRIES are not matching.

mssg. '***ERROR***' object 'CANNOT BE ASSIGNED VALUE'

descr. The given object of the entered sentence cannot be assigned a value in a "worth" clause. Those words which can be assigned values appear as follows in the table of VALID LEXICAL ENTRIES: e.g., ARMS/NOUN,WORTH/...
↑

mssg. '***ERROR*** MISSING DOLLAR VALUE FOR WORTH CLAUSE'

descr. The word "worth" was not followed by a dollar amount in a "worth" clause.

mssg. '***ERROR*** INCORRECT PREPOSITION →' word

descr. The given word is not the preposition required by the given verb. The required preposition may be found in the table of VALID LEXICAL ENTRIES as follows: e.g., SELL/V3/N(-ABSTRACT) P(TO)/
↑

mssg. '***ERROR***' wordtype 'EXPECTED,'
'CHECK →' word 'OR WORD THAT FOLLOWS'
'***ERROR*** ILLEGAL SENTENCE'

descr. An improper positioning of a word in a sentence not in accordance with the grammatical construction described in section 2 of this manual will generate this message. The given wordtype (e.g., noun, verb, etc.) was next expected by the system.

mssg. '***ERROR*** UNRECOGNIZABLE WORD →' word

descr. The given word is not in the table of VALID LEXICAL ENTRIES.

mssg. '***ERROR*** MULTIPLE AGENT NOT PERMITTED WITH THIS VERB'

descr. The user has attempted to use more than one agent with a non-joint verb.

mssg. '***ERROR*** INVALID USAGE OF' word

descr. The given word is improperly positioned in the sentence. This is a general diagnostic message.

mssg. '***ERROR*** QUERY CANNOT BE SERVICED BY INTERPRETER'

descr. The stative variable queried either cannot be manipulated by the user or is not a stative variable.

<u>Messages Generated by Semantic Interpreter</u>

mssg. '***SEMANTIC ERROR*** AGENT1 IS THE SAME AS AGENT2'

descr. The subject and object agents are identical.

mssg. '***SEVER INTERPRETER ERROR***'

descr. Report this to authors along with the given run of the simulation.

Messages Generated by Production Systems

mssg. '***KERNEL CANNOT BE INTERPRETED***'

descr. The system cannot operate on this semantic kernel.

mssg. '***I/O ERROR***', '***STI ERROR***'

descr. Internal errors, report to authors.

6. PROGRAM DESCRIPTION

The PTP simulation consists of approximately four or five major modules. The whole of the simulation is governed by an assembler language monitor module. This monitor is the substance of the PTPCOM mode (see section 3). The other major modules and their respective programming languages are as follows (refer also to figure 6.1):

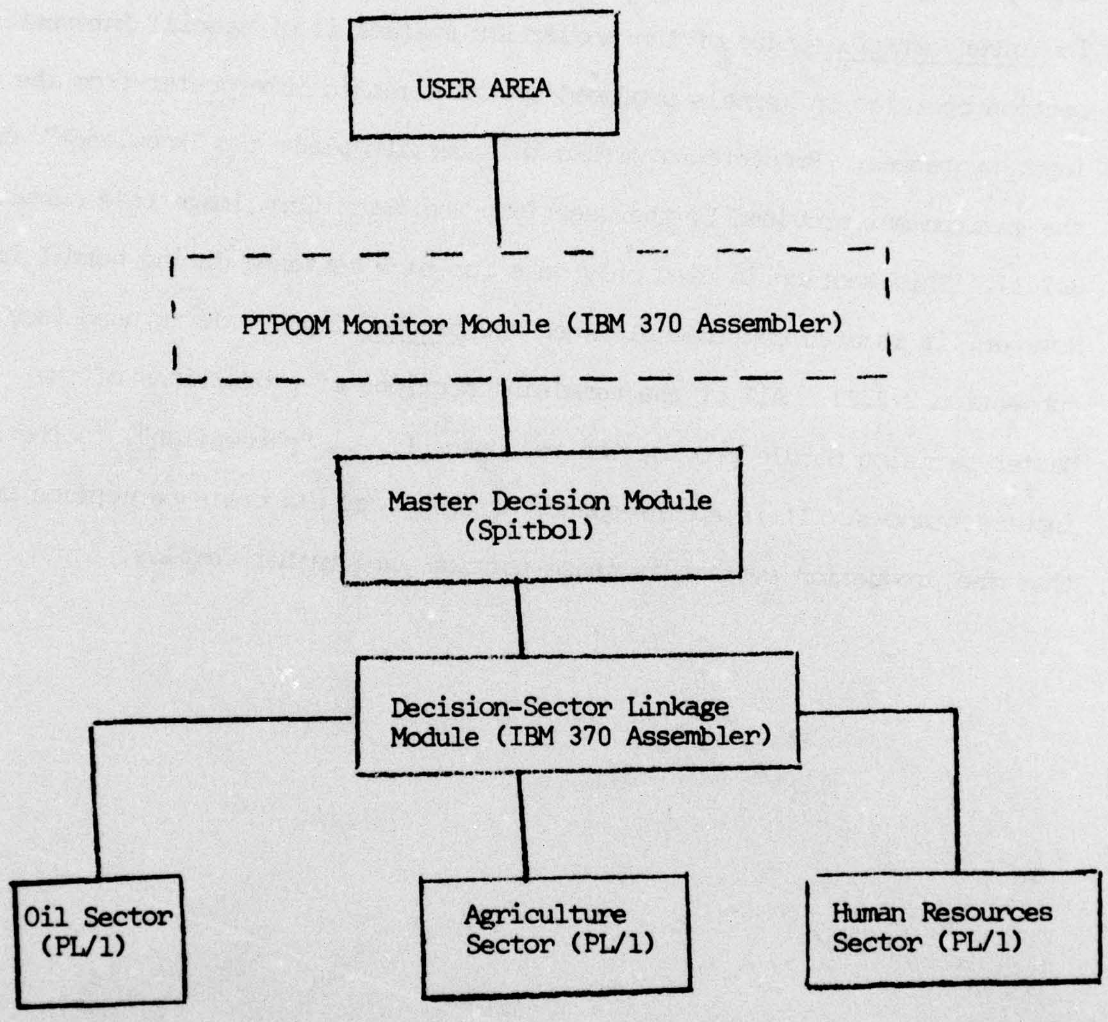
Module	Programming Language
Master Decision Module	Spitbol
Oil Sector Module	PL/1
Agriculture Sector Module	PL/1
Human Resources Sector Module	PL/1
Decision-Sector Linkage Module	IBM 370 Assembler

The actual code involved in these modules is beyond the scope of this manual.

The Master Decision Module is divided logically into several sections. The first section contains only Spitbol production system functions. This is followed by the simulation grammar (lexical parser and semantic interpreter). Execution of the grammar is sequential. That is, once an input sentence has been introduced to the grammar, it is first parsed by the lexical portion of the grammar, and then interpreted by the semantic portion of the grammar. The final section (the bulk of the decision module) is the set of simulation productions.

The production system is further divided into the nine subsections described in subsection 3.2.1 of this manual (concerning the 'COND' parameter). The Interpretation phase of the production systems is of special interest. This section operates on kernels produced by the semantic interpreter from the input sentences. Productions within this section place the "knowledge" about the environment provided by the user into the Short Term Image (see subsection 3.2.1). This section is used only once for each sentence during normal input. However, it is used continuously when the batched input mode is used (see subsection 2.3.2). All of the remaining sections of productions of the Master Decision Module provide the responses (i.e., "perception") to the user input sentences. It is a consequence of this most elaborate perception scheme that the production systems in these sections are rather complex.

Figure 6.1


USER AREA
PTPCOM Monitor Module (IBM 370 Assembler)
Master Decision Module
(Spitbol)
Decision-Sector Linkage
Module (IBM 370 Assembler)
Oil Sector
(PL/1)
Agriculture
Sector (PL/1)
Human Resources
Sector (PL/1)

Axiomatic Theories of Preference-Based
Choice Behavior: An Overview*

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INTRODUCTION

At least since the publication of Snyder, Bruck and Sapin's Foreign Policy Decision Making (1962), political scientists have been self-consciously aware that the study of politics involves, at least in part, the study of political decision-making. While there are a variety of definitions of "decision-making," most all treatments suggest that it involves a person (or set of people) making choices from some set of alternatives. That is, a theory of decision-making must include a theory of choice behavior. For example, after reviewing a variety of definitions of decision-making, Kirkpatrick (1975: 41) concludes, "the focus of this review reflects sympathy with a social process approach emphasizing the search for, and choice between, alternatives . . ." Similarly, Steinbrunner (1974: 16) defines a decision as a "choice made in pursuit of some purpose." These characterizations of decision making are very much in the spirit of the Snyder, et al (1962: 90) proposal to define decision-making as ". . . a process which results in the selection from a socially defined, limited number of problematical, alternative projects of one project intended to bring about the particular future state of affairs envisaged by the decision-making."

The purpose of this essay is to examine some axiomatic theories of individual choice behavior.* Such theories are, in general, based upon assumptions relating a person's preferences to his choices. Such assumptions are frequently termed "rationality assumptions". Therefore it will be useful first to identify several of the ways rationality has been used and to consider how reasonable such assumptions are with respect to political actors. Next,

---

*The area of game theory is specifically being excluded from the scope of this essay (although some game theoretic solution concepts and utility assumptions will be discussed). For a very readable introduction to game theory see Luce and Raiffa (1957).

a variety of theories of individual choice based upon these assumptions will be discussed. Since these theories of individual choice are sometimes used in political science to investigate problems of collective choice (i.e., questions of how individual choices relate to social choices) it will be necessary also to consider several theoretical approaches to "collective" choice. Finally, a concluding section will attempt to relate ATC to general questions of political decision-making.

AXIOMATIC THEORY

Since this essay deals with axiomatic theories of choice, it seems appropriate to begin with a brief general discussion of the method employed in developing these theories. It is important that a treatment of method precede more substantive concerns since the substance can best be understood and evaluated in the context of the method used to generate it.

From a rather abstract perspective, a theory can be viewed as a set of sentences asserted to be true of something. A theory of choice behavior could thus be seen as a set of statements asserted to be true (of some aspects) of choice behavior. One quite reasonable approach to the construction theory is to attempt to identify a set of empirically generated "facts" and then attempt to order these facts through an inductively identified theory. Another approach (and these approaches differ more in emphasis than in absolute terms) is to posit some reasonable assumptions (axioms) and to then investigate the deductive implementations of these assumptions. If the axiomatic approach is taken, the theorist is concerned with theories in which the set of sentences in the theory are closed under deduction. The "closed under deduction" property requires that if a set of sentences is in the theory, then so are any sentences logically deducible from those sentences. The axiomatic theorist is committed not only to the theory sentences actually written down, but also to any sentences which can be deduced using those sentences together with some rules of logic.

There is, however, no one common set of axioms which is shared by all axiomatic theories of choice. Instead, there are a number of different axiom sets each of which seems to be applicable in some contexts but not in others. These various axiom sets do share a common core idea - that a person's choice behavior should be (or is) relates to his preferences. This core notwithstanding, there is no one dominant axiom set to which the student of political decision-making can turn. Theorists of choice have themselves noted that there seems to be a lack of cumulation in the area of theories of choice behavior. For example, in their introduction to the first volume in the Contemporary Development in Mathematical Psychology series, Krantz, et al (1974) commented on the failure to include a paper in the area of preferential choice by noting: "There is no lack of technically excellent papers in this area, but they give no sense of any real cumulation of knowledge. What are the established laws of preferential choice behavior? (Since three of the authors have worked in this area, our attitude may reflect some measure of our frustration)" (Krantz, et al, 1974: xii). In spite of this general lack of an accepted axiomatic base, there are some commonalities of approach which will be worth examining. First, however, it might be helpful to consider briefly the kinds of results for which the deductive theorist is looking. This discussion will focus upon the analytic properties of results. Subsequent sections will treat the descriptive and prescriptive adequacy of the results.

The formal theorist works by positing plausible assumptions (axioms) and seeing where they lead (theorems) and therefore it is quite natural that he have a number of concerns relating to the logical properties of the assumptions made in the theory. In order to evaluate work done by formal theorists of choice it is necessary to see why (at least within the context of deductive theory) these concerns are reasonable and important.

The first of these is that the assumptions (axioms) be consistent; that they not contradict one another. A theory is said to be consistent if within the theory a single sentence cannot be proven both to be true and to be false. Concern with consistency arises, of course, from the feeling that two propositions p and $\sim$p cannot both be true together in the same system. This feeling--that at least one of the two propositions must be false--is termed the "principle of contradiction." Just as the principle of contradiction tells us that p and $\sim$p cannot both be true, so the "principle of the excluded middle" asserts that p and $\sim$p cannot both be false. Combining the principles of the excluded middle and contradiction we have the principle of alternativity which claims that given p and $\sim$p, one of the propositions must be true and the other false. The reason for the importance of the consistency requirement is that under most conventional logics, from inconsistent axiom sets, every single assertable proposition can be deduced as a theorem. Every sentence and its negation follows immediately from inconsistent axioms.

Arrow's General Impossibility Theorem [see Section], for example, shows that several reasonable descriptive and normative assumptions about individual and social choice are inconsistent. Among other things, Arrow's Theorem shows that the sentence "There does not exist a dictator" and the sentence "There does exist a dictator" can both be prove given apparently reasonable assumptions. Given the importance of consistency, it is not surprising to find that demonstrations of inconsistency (or so-called "impossibility" theorems) are frequently encountered in the choice literature.

A second concern is with the "weakness" of the assumptions in a theory. Weakness here is generally a desirable property. The weaker or less restrictive assumptions are, the less must be true of the world for the assumptions to

be acceptable. The formal theorist would like to be able to prove as much as possible assuming as little as possible. Given this concern, it again should not be surprising to find that considerable work in choice theory relates to the weakening (or generalizing) of assumptions.

Third, to the extent that theories of choice are intended to be descriptive, theorists are concerned that assumptions fit empirical knowledge about choice behavior. The discussion of rationality in the next section will serve as illustration of how empirical evidence helps to shape assumptions within formal theories of choice. In general, it is probably fair to characterize the strategy of the formal theorist as one of biasing assumptions toward what is (believed to be) known and leaving assumptions as unbiased as possible with respect to what is not known. Again, much work done by theorists focuses either on modifying assumptions to see how results are affected or showing that "accepted" assumptions are in fact biased in interesting ways with respect to what is not known. With these concerns in mind, it is possible to turn to a more substantive discussion of what formal theories of choice have to offer to the student of political decision-making.

INDIVIDUAL PREFERENCE, CHOICE, AND RATIONALITY

Preference-based theories of choice attempt to describe (or, in some cases, prescribe) observable choices in terms of underlying preferences. In this sense, preferences are thought of as being relative both to individual people and to time. Thus a preference is a preference of a particular person at a specific point in time. In this section, however, it will be convenient to be a bit more abstract and consider the preference relation "is preferred to" without specifying particular people and times. Nonetheless, it should always

be remembered that different people may have different preferences and a particular person's preferences may well change over time.

Preferences are generally thought to obtain between alternatives.* A person might, for example, prefer the alternative of not voting in a particular election to the alternative of voting. In such cases, it appears reasonable to expect there to be some relation between a person's preferences and his choice behavior. For example, if it were known that a person in November of 1976 preferred the alternative not voting in the presidential election to the alternative of voting, we would expect, all other things being equal, the person to choose not to vote in the election. Theories of choice which are based upon such assumptions may be termed preference-based theories of choice. The specific assumptions linking preference and choices are termed rationality assumptions. The purposes of this section will be to first, propose a very general definition of preference based rationality, and to then identify a variety of more specific assumptions about preference and illustrate some of the implications of these assumptions for choice behavior.

Theories of choice behavior are frequently categorized with respect to assumptions made about the decision environment. For example, a common categorization distinguishes between choice behavior under certainty, under risk and under uncertainty. Environments involving certainty are those in which a chosen alternative leads to certain and known consequences.
A person is in a risky environment if alternatives lead to consequences with known probabilities. Finally, an uncertain choice environment is one in which alternatives lead to consequences with unknown or undefinable probabilities.

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*An alternative may be thought of as a particular state of th world in the sense of Arrow (1963).

In all of these situations, the preferences of the choser are generally assumed to be certain. Any uncertainty or risk comes from his knowledge of the external world or "the state of nature." Since theories of choice behavior under certainty are, in many cases, the simplest, they will be treated first.

A second distinction worth keeping in mind concern whether a particular ATC is to be viewed as descriptive or prescriptive. If the objective of the theory is the former, the central question is whether the theory appears to be true of the empirical world. If, on the other hand, the intent of the theory is prescriptive the relevant question is whether (and in what specific circumstances) a decision-maker would be wise to choose in accord with the theory. Obviously this distinction will often be blurred since if a decision maker accepts a theory as providing good prescriptive advice, the theory will also be useful in describing the behavior of that decision-maker. Having made these distinctions we will turn to the problem of choosing in a certain decision environment.

RATIONALITY

People make choices. Implicit in the notion of choice is the idea that something was selected or chosen where something else could have been selected. In general it seems reasonable to assume that there is some relation between the preferences a person has for available alternatives and the alternative he selects. A little notation will make this discussion far more compact. Let X represent a set of alternatives and χ represent a set of nonempty finite subsets of X. More concretely, suppose a person has three alternative ways of spending a particular evening: (1) attend a precinct caucus (PC), (2) attend a baseball game (BG), (3) watch television (TV). In terms of the notation:

$X = \{PC, BG, TV\}$

$\chi = \{\{PC, BG, TV\}, \{PC, BG\}, \{PC, TV\}, \{BG, TV\}, \{PC\}, \{BG\}, \{TV\}\}$

The set χ contains as elements sets of alternatives (in this case all such nonempty sets) the individual might be considering. The elements of χ are termed presentation sets. The pair $\langle X, \chi\rangle$ can be termed (following Richter, 1971) a choice space. Choice spaces are sets of choice problems where given an element (presentation set) of χ the task if to choose one or more elements from the presentation set. At a very general level, a choice from a presentation set can be said to be rational if the choice is made in accord with the chooser's preferences. This notion of rationality as a relation between preferences and choices while intuitively pleasing is potentially troublesome since behaviorally, only choices can be viewed. Preferences remain hidden except as revealed through choices. Thus, in a survey a respondent's preferences over various candidates for President cannot be observed directly and instead must be inferred from choices made when presented with various sets of alternatives. A behaviorally useful definition of rationality must avoid the empty claim that anything chosen is rational since the thing chosen is "obviously" preferred to that which was available but not chosen.

Since choices are made from presentation sets (elements of χ), Richter (1971: 31) suggests defining choice (with respect to a choice space) as a rule defined on χ which for <u>every</u> presentation set in χ designates a non-empty subset of presented alternatives. This subset of the presentation set is termed the choice for that presentation set. In the example above, consider the presentation set consisting of "going to the baseball game" and "attending a precinct caucus," (i.e., $\{BG, PL\}$). Suppose a person decided only to "go to the baseball game." Such an event would entitle us to say that "going to

the baseball game" was chosen, when "attending the precinct caucus" could have been chosen. Presumably, such a choice would be said to be rational if the person preferred going to the baseball game to attending the caucus.

To say that a person prefers going to a baseball game to attending a precinct caucus is to establish a relationship between the two alternatives. More generally, "is preferred to" can be viewed as a binary relationship defined over the alternatives in (X). Exactly what properties the preference relation might be assumed to have is a matter of some controversy (and consequence) and is a topic to which we shall return shortly.

First, however, there is now enough conceptual apparatus to propose a very general definition of rationality. Recall that it was suggested that a choice be termed rational if it is in accord with the chooser's preferences. More precisely, (following Richter, 1971) a preference relation is said to rationalize a choice on a choice space if for every presentation set, the choice produced is the set of most preferred elements in the presentation set. Choices which can be rationalized in this sense are termed rational. One important implication of this definition is that there do exist choices which are not rational. Thus the definition is not circular. As an example consider the following two presentation sets:

PS_1: {BG, PC, TV}

PS_2: {PC, BG}

Suppose a person chose "PC" in PS_1 and "BG" in PS_2. According to the above definition, these choices would not be rational since "PC" cannot be "most preferred " in PS_1 and not in PS_2 (since "BG" is available in both). This example, of course, depends upon an implicit assumption that the person's preferences are not changing.

Thus we have a very general (yet non-circular) definition of rationality. This definition is more general than the rationality assumptions which have been generally used. In order to get to these more commonly encountered definitions, it will be necessary to make more assumptions about the nature of the preference relation. It should, however, be kept in mind that the assumptions which follow are "special cases" and one may reject most any of them and still assume people to be rational in the sense identified above.

Let us symbolize the "is preferred to" relation by the symbol P, the relation "is indifferent to" by the symbol I and the relation "is preferred or indifferent to" by the symbol R. Another common way of rendering the weak preference relation R is to read aRb as "alternative a is 'at least as good as' alternative b" to some chooser at some time. Using this notation, aPb if and only if aRb and not bRa . Some powerful properties frequently assumed to hold for R, and I are:

1) <u>connectedness</u>: for any pair of alternatives in X, either aRb or bRa (or, equivalently, aPb or bPa or bIa)
2) <u>reflexivity</u>: for any alternative in X, aRa
3) <u>transitivity</u>: for any three alternatives in X, aRb and bRc implies that aRc.

Preference orders satisfying the above three axioms are termed weak preferenced orders. These axioms are of central importance to many rational choice theories in political science, economics and psychology. Thus it will be useful to consider the reasonableness of each of them separately.

A psychological interpretation of the connectedness property is that the chooser can compare each pair of the alternatives in X with respect to

preference and indifference. This assumption seems quite reasonable in situations where a person produces a set of alternatives himself. It is possible, however, that in some cases where X is in part determined by others (e.g., "socially" determined) the individual may be unable to identify any dimension of comparison among some of the alternatives and thereby be unable to prefer one to the other or to be indifferent among them. Such possibilities are discussed in Riker and Ordeshook (1973: 16-17).

The reflexivity condition appears totally unobjectionable. It is difficult to imagine a person refusing to admit that an alternative was at least as good as itself. If such a person were to be found we would likely doubt that he understood what was meant by "is at least as good as."

The transitivity assumption is perhaps the most controversial. In order to see the basis for the controversy it will be useful to consider separately the question of transitivity of I and the question of the transitivity of P. Most objections to transitivity focus upon requiring I to be transitive. The classic example deals with adding sugar grain by grain to a cup of coffee. A person might be unable to detect a sweetness difference between a cup of coffee with no sugar and with one grain of sugar. Nor, in fact, might he be able to discriminate any two cups of coffee which differed by only one grain of sugar. Yet, presumably at some point enough sugar would be added that the individual could discriminate coffee with lots of sugar from black coffee. Suppose this person prefers black coffee to "sweetened" coffee. Then we would have a person who is indifferent between two cups which differed by only one grain of sugar but who is not indifferent between black coffee and coffee with, say, a spoonful of sugar. In such a case a series of successive "indifferences" leads to a preference and therefore indifference is not transitive. Examples such as this one have lead some theorists (e.g.,

Fishburn, 1973) to develop theories which dispense with transitive indifferences.

There are, however, several aspects of such examples which reduce their impact. First, the example obviously depends upon a person's inability to discriminate certain differences. Such examples cannot be provided for strict preferences since to prefer *a* to *b* obviously requires that *a* be discriminable from *b*. Noting this, McKay (forthcoming) suggests restricting the transitivity assumption to perceptually distinct alternatives. Another way of accomplishing the same end would be restrict X (or at least elements of X) to alternatives which are discriminable to the chooser. This really does not appear to be all that great a restriction. Recall too that there is no universal theory of choice - only a set of theories. Thus we should not expect an assumption to be realized in all cases. Restricting the applicability of weak order assumptions to alternatives which are perceptually distinct does not seem unreasonable (though we shall have to return to this question when we consider the uncountably infinite alternative sets posited in spatial theories of electoral competition).

The second question relates to the transitivity of P. This needs to be considered on both conceptual and empirical grounds. Suppose a person in 1968 is offered a choice between Humphrey and Nixon and chooses Humphrey. He is then offered a choice between Nixon and Wallace and chooses Nixon. Finally, when presented with Wallace and Humphrey, he selects Wallace. These choices (and the preferences presumed to underly them) are intransitive. We have *HPN*, *NPW*, and *WPH*. What can we say of such a person? There seem to be essentially two tacks which might be taken. First, it could be noted that preferences are relative to time and perhaps the individual has changed his preferences in the course of our presenting him with alternatives. Such a possibility always exists (since we can observe only choices and not preferences and we can only observe

one choice at a time). In such situations an assumption of algebraic transitivity which ignores time (i.e., the dynamics of the choice process) will fail to capture important behavioral aspects of the problem.

A second possibility is that the person at one time point has intransitive preferences. Such a possibility seems to me to violate the very meaning of preference. As an example, consider a situation (due to Davidson, et al, 1955) where a department chairperson offers Mr. S. three options: (*a*) a full professorship at $5,000, (*b*) an associate professorship at $5,500, and (*c*) an assistant professorship at $6,000. Davidson, et al (1955: 145) suggest that S. might reason: *a*P*b* since the advantage in kudos outweighs the small difference in salary; *b*P*c* for the same reason; *c*P*a* since the difference in salary is now enough to outweigh a matter of rank." The question is, are such intransitive preferences reasonable? Clearly they are not rational (even in the very general sense defined earlier) if it is assumed that S. will choose from distinct pairs in accord with his preferences. Moreover, there are strong prescriptive reason why a person would be unwise to allow such intransitive preferences to determine his choices. As an illustration, the chairperson might say to S.:

> ". . .'I see you prefer *b* to *c*, so I will let you have the associate professorship - for a small consideration. The difference must be worth something to you.' Mr. S. agrees to slip the department head $25 to get the preferred alternative. Now, the department head says, 'Since you prefer *a* to *b*, I'm prepared - if you will pay me a little for my trouble - to let you have the full professorship.' Mr. S. hands over another $25 and starts to walk away . . . 'Hold on,' says the department head, 'I just realized you'd rather have *c* than *a*. And I can arrange that - provided . . .'" (Davidson et al, 1955: 146)

What seems to be going on is that Mr. S. changes the dominant "dimension" of comparison from "rank" to "salary" as he considers different pairs of alternatives. However, a person choosing in such a fashion (i.e., in accord with the intransitive preferences) can quickly be divested of resources. Thus there seem to be solid grounds for advising a person not to make choices based upon intransitive preferences (see Schwartz, 1972, for an alternative account of this example). Such advice of course does not preclude the person from continuing to choose intransitively.

This is not to say that there are not empirical examples of intransitive choice behavior. There certainly are and they are well documented (e.g., see Tversky, 1969, May, 1973). Indeed, the empirical evidence against transitivity is so strong that one prominent scholar has claimed ". . . as a basis for psychological theorizing, algebraic transitivity [the sort of transitivity being discussed here] is dead. . ." (Edwards, 1961: 77). Again, it is important to note that the relevant question is not whether transitivity is always a descriptively reasonable assumption, but rather, in what decision environments transitivity can be expected to hold. Recent research by Buss (1976) provides surprisingly strong empirical support for the transitivity assumption. Buss asked first grade children who they would prefer to obey in each of four contexts ("working around the home," "working in the classroom," "being a citizen of the U.S.," and "in a time of war"). The alternative set (X) consisted of "mother," "father," "teacher," "principal," "vice-president," and "president." The presentation sets consisted of all the distinct two element subsets of X. This is an extremely stringent test for transitivity since these children are likely to be in either Piaget's preoperational stage of cognitive development or very early in the concrete operational stage. In either case Piaget would predict that the children would

not exhibit transitive reasoning. Yet Buss found very high level of transitive choice behavior in his first grade subjects. He reports similar (though slightly higher) results for fifth grade and college students. Further, he found it was possible to increase transitive choice behavior by letting the first graders ask questions about the various situations. This lends indirect support to the hypothesis that intransitivities are more likely to be encountered in situations involving unfamiliar alternatives.

Nonetheless, it is clear (Tversky, 1969; Buss, 1976) that the degree of transitivity exhibited by choosers can be experimentally manipulated. This is the case in certain, as well as risky and uncertain, environments and suggests that additional attributes of the decision environment must be specified before transitivity can be justified on descriptive grounds. These traits appear to be related to the "complexity" of the choice task.

RISK AND UNCERTAINTY

Weak preference orders (i.e., preference orders where R satisfies the **axioms** of connectedness, reflexivity, and transitivity) are useful not only because in many situations they appear quite reasonable, but also because they can be faithfully represented by utility functions. A set of alternatives (X) together with the preference-indifference relation (R) will, in general, be non-numerical. That is, alternatives may consist of candidates, policies, etc. and not numbers. It will often be useful to be able to talk about preferences numerically. To do this it is convenient to define a utility function.* In decision environments involving certainty (such as that discussed above), a utility function is defined over the alternative set (X) and it can be shown that (except for certain uncountable alternative sets) for weak preference orders there will exist a (non-unique) real valued utility function on X such that

aPb if and only if $u(a) > u(b)$

In this sense, to assert that a person chooses his most preferred alternative is equivalent to saying he chooses that alternative which has associated with it the highest utility index. This is the notion of utility used in, for example, most work in spatial theories of electoral competition.

However, in decisions involving risk or uncertainty it is no longer reasonable to assume that a rational chooser will necessarily select the alternative with the highest associated utility since the chooser does not, by assumption, know for certain the state of the world when making his selection.

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*A utility function is a rule which assigns a number $u(a)$ to each alternative in I such that preference order is preserved in the numerical order.

Such choice problems are frequently investigated in terms of a "payoff matrix" whose rows (a_i) correspond to alternative actions and whose columns (θ_i) correspond to the possible "states of nature." The entries in the cells of the payoff matrix (o_{ij}) then represent the outcome that occurs when a particular choice is made and a particular state of nature obtains. Decision-makers are assumed to have a weak preference order over the outcomes. As a simple example, consider the following payoff matrix for a person deciding whether to carry an umbrella on a walk.

	States of Nature	
Alternative Actions	θ_1: rain	θ_2: no rain
a_1: carry umbrella	o_{11}: stay dry carry umbrella	o_{12}: stay dry carrying the umbrella
a_2: do not carry umbrella	o_{21}: get wet without carrying umbrella	o_{22}: stay dry without carrying the umbrella

If the decision-maker knew whether it would rain, then the choice problem would be one under certainty. If he could assign probabilities it would be decision-making under risk, and if there was no knowledge of probabilities it would be choice under uncertainty. Since choice under certainty has already been discussed, let us now look at theories of choice which have been developed for risky situations.

The basic theory to be presented was developed by Von Neumann and Morgenstern (1947). They identified and justified some axioms about preferences which, if satisfied, guarantee that a person's choice behavior can be rationalized as the maximization of his <u>expected</u> utility. Von Neumann and Morgenstern's purpose in developing these axioms was prescriptive. They felt

the axioms described how a rational decision maker ought to behave. However, there has been considerable empirical work investigating the descriptive adequacy of the axioms as well. The basic idea behind the Von Neumann and Morgenstern analysis was as follows. Consider a gamble in which you either win or lose $500. If you refuse to gamble, you neither win nor lose and your winnings are $0. It would seem reasonable to assume that your choice of whether to accept the gamble will depend upon (your perception of) the probability of your winning. The higher the probability of winning, the more willing you would be to gamble. Further, there will be some probability of winning such that if the probability is any lower you will refuse to gamble, and if it is any higher you will accept the gamble. At precisely this point you are indifferent between gambling and not gambling. Thus, they argued, at this probability your expected utility from gambling should be precisely equal to your expected utility of not gambling. Based upon an axiomatic treatment (included in the axioms is the requirement that the chooser have a weak preference order over the outcomes) of this sort of reasoning (see Luce and Raiffa, 1957 for a very readable discussion of the axioms), Von Neumann and Morgenstern were able to prove the existence of a utility function (u) over outcomes (o_{ij}) such that a person who chooses that alternative action (a_i) for which the expected utility ($\Sigma_j p_j \cdot u(o_{ij})$) is at a maximum always chooses in accord with his preferences over the outcomes. Thus a person's choice behavior is considered rational if it maximizes his <u>expected</u> utility. It is important to note that the proof of existence of such a utility function does not depend on being able to make choices over a repeated set of trials and thus the theory is applicable to "one time" decision situations.

While the expected utility (EU) approach appears to make intuitive sense, there is one well known example (due to Allais (1953) and discussed in Coombs, Dawes, and Tversky (1970: 126-128)) which both illustrates the EU approach and suggests that caution be exercised in applying EU theory. Consider the following two situations each of which involves gambles expressed in millions of dollars.

<u>Situation 1</u>. Choose between

Gamble 1. Win 1/2 million dollars with probability 1;

Gamble 2. Win 2 1/2 million dollars with probability .10;
Win 1/2 million dollars with probability .89;
Win 0 dollars with probability .01.

<u>Situation 2</u>. Choose between

Gamble 3. Win 1/2 million dollars with probability .11;
Win 0 dollars with probability .89;

Gamble 4. Win 2 1/2 million dollars with probability .10;
Win 0 dollars with probability .90.

Apparently most people will prefer Gamble 1 to Gamble 2 since it guarantees they become rich. Further, most people Gamble 4 to Gamble 3 since a small difference in the probability of winning is dominated by a large difference in the amount to be won. These choices, reasonable though they appear, are inconsistent with the expected utility principle. This can be seen by noting that the choice of Gamble 1 over Gamble 2 implies:

$$u(\text{gamble } 1) > u(\text{gamble } 2)$$

or

$$1 \cdot u(1/2 \text{ m.}) > .10u(2\ 1/2 \text{ m.}) + .89u(1/2 \text{ m.}) + .01u(0)$$

or

$$.11u(1/2) > .10u(2\ 1/2) + .01u(0)$$

Similarly, the choice of Gamble 4 over Gamble 3 implies:

$$u(\text{gamble } 4) > u(\text{gamble } 3)$$

or

$$.10u(2\ 1/2 \text{ m.}) + .90u(0) > .11u(1/2 \text{ m.}) + .89u(0)$$

or

$$.10u(2\ 1/2\text{m.}) + .01u(0) > .11u(1/2 \text{ m.})$$

These two inequalities are obviously inconsistent and thus the "reasonable" choices cannot be rationalized by appeal to EU. One response to such examples is, of course, to say that the choices were only apparently reasonable and that EU theory should be followed as normative guide. After a re-examination of our preferences, we would revise our choices to make them consistent with EU theory. MacCrimmon (1967) tested this claim by showing Allais-like problems to upper-middle-level executives. His conclusion was that the executives tended to regard deviations from EU theory as mistakes and would change their decisions to make them consistent with the theory if given a chance. Nonetheless, these findings certainly indicate caution in applying EU as a descriptive theory.

A second response is to question the assumptions of the EU model which lead to the "funny" results. The questionable assumptions seem to be those which permit gambles to be considered as being "context free" in the sense that all that counts in evaluating and comparing gambles is the desirability of and probability of outcomes. "The problem seems to be that receiving 0 in the context of gamble 1 is different from receiving 0 in the context of gamble 2. But this in turn raises doubts about the substitutability and reduction . . . axioms of the EU model. (Fiorina,1975: 10)"

A further criticism of the EU model has been that it requires that probabilities of outcomes be known in advance. Savage (1954) has developed

a set of axioms based upon subjective probability assignments. Savage's axioms lead to a result similar to that of Von Neumann and Morgenstern only now the rational individual acts so as to maximize subjective expected utility (SEU). Savage's SEU theory is a generalization of EU since it allows for individual differences in both the identification of utilities and the probability of events. Unfortunately, SEU is also subject to puzzling examples similar to that presented above. Perhaps the most familiar is that due to Ellsberg (1961) and discussed in Fiorina (1975).

The SEU theory tends to collapse the distinction between risky and uncertain decision environments made earlier by permitting subjective probability estimates to be used even if "objective" probabilities are unevaluates. Nonetheless, there may be situations where information about probabilities is so suspect that we wish to ignore the information in reaching decisions. Ferejohn and Fiorina (1974) suggest the choice of whether to vote is, for many people, such a decision. There are a plethora of criteria which have been suggested as being appropriate in such situations. A brief description of five such "decision rules" should suffice to alert the reader to the difficulties in making predictions about behavior in uncertain situations without prior knowledge about the specific decision rule being employed by the decision-maker.

The following are a sample of some "reasonable" decision rules for choosing in uncertain environments. Milnor (1954) and Coombs, Dawes and Tversky (1970) provide a more extended discussion of each of the decision rules.

1. Principle of insufficient reason: This criterion transforms uncertainty to risk by assigning equal subjective probabilities to all states of nature. This assignment is justified on the grounds

that if the chooser is really uncertain as to the probabilities of the various states of nature, then the states should be considered equiprobable. However, unless the decision-maker is using a minimal state representation (and, given the degree of ignorance being assumed, this is unlikely), the identification of states is arbitrary (i.e., another set of states could have been used) and thus so are solutions based upon this principle.

2. Maximin Criterion: This criterion advises the selection of that alternative whose minimum payoff is at a maximum. This principle is quite conservative and is based upon an implicit assumption of a "hostile" nature. For this reason, this criterion is central in the theory of competitive games.

3. Maximax Criterion: This criterion suggests selection of that alternative whose maximum payoff is the maximum. This maximax criterion is optimistic in the same sense that the maximum criterion is pessimistic.

4. Hurwicz Pessimism-Optimism Criterion: This generalizes criterion 2 and 3 and weighs the best and worst payoff for each alternative by some constant α, $(0 \leq \alpha \leq 1)$ called a pessimism-optimism index. The "value" of an alternative is then α(maximum payoff) + $(1-\alpha)$ (minimum payoff) and the choice is that alternative with the highest "value." When $\alpha=1$ this criterion reduces to the maximum criterion and when $\alpha= 0$ it reduces to maximax.

5. Minimax Regret Criterion: This criterion suggests associating a regret matrix with the payoff matrix. Each entry of the payoff matrix is the arithmetic difference between the payoff that obtains and the maximum payoff that could obtain if the true state of nature were known in advance. Like the maximin criterion it focuses upon

the worst case. This criterion was used by Ferejohn and Fiorina (1974) in their analysis of the decision whether to vote. A difficulty in using these criteria to make predictions (or recommendations) about behavior is that there exist situations in which each criterion will suggest a different action (e.g., see Coombs, et al, 1970: 142). Thus while each criterion may appear reasonable, they are capable of producing quite different choices. What is needed to make predictions about choice behavior is an independent theory of the selection of decision rules (e.g., see Chernoff, 1954). Such a theory would seem, once again, to have to take into account decision "context" as well as attitudes toward risk on the part of the decision-maker (e.g., see Coombs, 1974).

STOCHASTIC THEORIES OF CHOICE

All of the theories considered to this point have assumed that a chooser's preference order over alternatives (outcomes) is a weak order and is deterministic. Any probabilities are assumed to refer to knowledge about the world and not knowledge about preferences. There are, however, a number of axiomatic theories of choice which, rather than view the preference relation as deterministic (aPb), posit that it only makes sense to refer to the probability that a is preferred to b by an individual. These stochastic theories of choice were developed in order to account for the empirical observations that people frequently make different choices under what appears to be identical conditions and that choice behavior is often intransitive. This lack of consistency may be attributable to changing tastes, etc. (in which case a deterministic theory would seem "ultimately" to be appropriate) or it may be attributable to an underlying psychological mechanism which itself is stochastic.

Stochastic theories of choice tend to fall into two categories: constant utility theories and random utility theories. In constant utility theories the assumption is made that alternatives have a fixed utility and that choice behavior is a function of the distance between the utilities of the alternatives in the presentation set (e.g., see Luce (1959)). Random utility theories, on the other hand, assume that the alternative with the highest utility is always chosen, but that the utilities themselves fluctuate (e.g., see Coombs probalistic unfolding theorem). It is important to note that the probabilities one posited to arise from properties of the individual chooser. They do not arise from pooling data from a number of subjects (in fact several such theories can be tested only at the individual level and can be formally shown not to hold for pooled data).

While the various stochastic theories have received some empirical support, they are, unfortunately, not immune from logical problems of the sort discussed in connection with the expected utility theories. For example, Luce (1959) developed a theory to explain relationships between situations in which a person is asked to choose one alternative from a larger presentation set and situations in which the person is asked to rank order (from most preferred to least preferred) the alternatives in the presentation set. A main result of his theory was what has become known as "Luce's Choice Axiom." Luce's Choice Axiom has received empirical support. However, if one additionally assumes that people rank order alternatives in reverse order (i.e., from least preferred to most preferred) and select their least preferred alternative from a presentation set in accord with Luce's axioms, then it follows that any alternative is preferred to any other alternative with an equal probability (see Thorson and Stever, 1974 for proofs). In other words, it can be proven that preferences are uniformly random. Given the reasonableness of the reversability assumptions, one is led to regard Luce's theory with some suspicion.

While the range of theories of individual choice has rarely been touched upon, enough different sets of assumptions (and attendant problems) have been presented to give a flavor of the approach taken by the axiomatic theorists. Before discussing the relevance of this approach to the study of political decision-making, let us briefly examine how some of these theories have been used by political scientists (and others) to examine problems of social choice.

SOCIAL CHOICE

Theorists working with axiomatic theories of choice are very much committed to the individual as the relevant unit of analysis. It is, after all, the individual who can properly be said to have preferences. Thus is should not be surprising to find that when rational choice theorists turn to questions of social choice, their interest is in such problems as how (i.e., through what mechanisms, procedures, etc.) individual choices become aggregated into social choices (where the society is the collection of individuals) and what "properties" resulting social choices will have. There are a number of excellent reviews of work in this area (e.g., Barry, 1970; Riker and Ordeshook, 1973; Taylor, 1971; Ordeshook, 1974; Weisberg, 1975; Plott, 1976) so this section will be relatively brief and will attempt to identify general directions rather than specific findings.

One area of considerable effort has involved examining the properties of different voting procedures. The basic question in this regard has been whether there will exist voting procedures (or social welfare functions) which will produce social choices (or social "preference" orders) which meet certain conditions. The major work in this area is, that of Arrow (1963) (for an extremely readable review of Arrow's assumption and results see Plott,

forthcoming). Suppose we have three people with the following preferences over an alternative set consisting of Humphrey (H), Nixon (N), and Wallace (W).

1. *HPN*, *NPW*, *HPW*
2. *NPW*, *WPH*, *NPH*
3. *WPH*, *HPN*, *WPN*

These preferences are, for each individual, transitive. Yet note what happens if the preferences are aggregated to a group "preference" on the basis of a majority vote over the two element subsets (assuming, of course, the people vote for that available alternative which is highest in their preference order). In an election between Humphrey and Nixon, Humphrey wins two votes to one. In a Nixon-Wallace race, Nixon wins two to one. Finally, in a Humphrey-Wallace election, Wallace defeats Humphrey two to one. If the group's "preferences" are thought to be identified with the results of the voting, we have

Group: *HPN*, *NPW*, *WPN*

The group's "preferences" are intransitive and we have an example of the "paradox of voting."

Arrow vastly generalized the "paradox" by proving that no voting procedure involving more than two alternatives and more than two rational (in the sense of their having weak preference orders) voters could satisfy the following seemingly innocuous ethical conditions and produce a transitive social "preference" order:

1. <u>Unrestricted Domain</u>: The voting procedure must accept any of the logically possible preference orders from any of the voters.
2. <u>Independence of Irrelevant Alternatives</u>: The social "preference" between any two alternatives *a* and *b* depends only upon the voter's ordering of *a* and *b*.

3. <u>Pareto Principle</u>: If all the voters prefer a to b then so shall society.

4. <u>Non-Dictatorship</u>: There exists no individual whose preference order is always the same as society's <u>regardless</u> of the orderings of the other voters. This condition prohibits the existence of a dictator.

Arrow proved the conditions described above (including the requirement that voters have weak preference orders) are <u>logically</u> inconsistent. This result has generated considerable research. Some of it attempted to remove the inconsistency by modifying the conditions. Black (1958), for example, has shown that if condition 1 is modified to allow only "single-peaked" preference orders then the new set of conditions are not inconsistent. Others have attacked condition two as being unreasonable (see McKay. forthcoming, for a summary of the criticism of this condition as well as other of Arrow's conditions).

Another line of argument (Fishburn, 1970; Riker and Ordeshook, 1973) has been that we should not expect "coherent" (in the sense of transitive) social choices. Such expectations are based upon a prior category error of predicating properties to groups that properly belong only to individuals. "There is no reason to expect consistency in social outcomes, however, for they are not selected to maximize anything, merely to reflect the views of majorities or of groups selected by other methods of summation" (Riker and Ordeshook, 1973: 84). Fishburn (1970) provides several very clever examples to illustrate that social transitivity is inconsistent with the principle that any candidate who receives all or all but one of the votes should win.

If the thrust of Arrow's result can be thought of as negative (in the sense of showing that a certain thing which appears to be desirable cannot be had), then so can efforts in the area of "spatial" theories of electoral competition. Spatial theory here refers to work arising out of a part of Down's (1957)

An Economic Theory of Democracy. The general approach is to assume a world of voters with weak preference orders over an n-dimensional Euclidean "issue space." The "dimensions" of the space are loosely interpreted as "issues" and a point in the issue space can be thought of as a potential party platform. Citizen's preferences over the points in the issue space are represented by utility functions. Generally, two candidate majority rule elections are studied and a candidate is represented by a point in the issue space. Typically voters are assumed to vote for the candidate whose position has associated with it the highest utility (in the spatial analog, to vote for the candidate "nearest" the voter's ideal point). Since candidates are also assumed to be rational, the major focus of spatial theory has been upon candidate strategy under different assumptions concerning the distribution of voters in the issue space. More precisely, the concern has been to identify necessary and/or sufficient conditions for the existence of *equilibrium points* - points from which a rational candidate would have no incentive to move since they would not lose to any other point. Ordeshook (1974) provides a clear analysis of the assumptions of the various spatial theories.

Spatial theory differs from Arrow in several important respects. First, while Arrow assumed voters have preferences over a finite number of alternatives, spatial theorists consider alternative sets with an uncountably infinite number of alternatives. Thus the spatial theorist finds it necessary to identify utility functions for individuals. As was discussed earlier in the coffee example, assumptions of the existence of weak preference orders seem less compelling when the chooser is required to make infinitely fine distinctions (as he is in order to define continuous utility functions over uncountable alternative sets). Nonethless this assumption is no different than that made in general equilibrium analysis in economics. Second, voter's preferences

are assumed to be "single-peaked" with respect to each dimension (again, violating Arrow's first condition). It should be noted, however, that although these assumptions may appear restrictive, they are the same (or similar) to assumptions required to employ most multi-dimensional scaling techniques.

In terms of the search for conditions leading to the existence of majority equilibrium points, results have been generally negative. If there are more than two dimensions, the existence of such points generally depends very strictly upon the voters being symmetrically distributed about some point in the issue space. Such an assumption is, of course, unlikely to be met. In the one dimensional case, Downs (1957) shows the median is always an equilibrium point (assuming everyone votes). Similarly in two dimensions Wendell and Thorson (1974) prove the multi-dimensional median to be an equilibrium of certain rather restrictive assumptions apply to the citizen's utility functions.

Perhaps as a consequence of these results, efforts seem to be moving into more empirical areas (to attempt to identify the domain of applicability of spatial theory) and into attempts to identify weaker assumptions and weaker notions of equilibrium.

While axiomatic theories of choice have been applied in a number of additional political domains such as problems of public goods provision (Olson, 1965), regulation (Buchanan and Tullock, 1962), and coalitions (Riker, 1962, DeSwaan, 1973), a comprehensive survey is outside the scope of this essay. Hopefully this overview of Arrow and spatial theory provides the basis for a perspective from which some comments can be made about possible relations between axiomatic theories of choice and political decision-making. Such will be the task of the concluding section.

CONCLUSION

Throughout the preceeding lengthy (although by no means exhaustive) discussion of axiomatic theories of choice, the point was repeatedly made that there is no single accepted theory which accounts for all aspects of choice behavior. Rather, there are a number of theories - based upon different assumptions - which seem to "work" in some settings and not others. These theories do, however, have some commonalities. Central among these is the premise that choice behavior can be rationalized by reference to underlying preferences. Such a premise can be stated very generally as was done early in the third section or it can be made more restrictive as when the assumption is made that people have weak preference orders over some alternative set.

In evaluating the reasonableness of rationality assumptions with respect to political decision-making, it would seem that the appropriate question is not "are political decision-makers rational?" but instead, given the variety of rationality assumptions available, "in what contexts or decision environments do what kinds (if any) of rationality assumptions make sense?" Unfortunately this is not a simple question to answer. First, it is difficult because political science has no accepted theory of context to assist in determining which decision environments are similar and which are not. Second, most empirical tests of the various assumptions have been run in experimental settings specifically designed to eliminate as much context (with the exception of the certainty/risk distinctions mentioned earlier) as possible. This is, of course, good experimental design if one wants to know whether there exist situations in which certain data can be predicted by a particular theory. To the extent, however, that one concern is with the interaction between decision environment and appropriate rationality assumptions, decision environment variables must be explicitly included in the experimental design.

The point being made about context is really part of a larger argument to the effect that choice behavior is only one component of the "decision-making process." To study choice behavior in isolation from the rest of the process requires making some rather heroic assumptions about the decomposability of the entire process. These assumptions may be quite plausible to the economist interested in investigating properties of choice behavior under conditions of economic equilibrium (which make the decomposition reasonable). They may be less plausible in many political contexts where the focus is upon change (or at least where the case for equilibrium has yet to be made). Thus, for example, we would expect a political campaign to have an impact upon citizen's preferences and would be suspicious of a theory which focuses only upon the impact of people's preferences upon candidate behavior by asserting that preferences were being taken as "givens." This is not to say that rational choice theories are inappropriate to voting behavior. It is to say, however, that a rational choice theory which takes preferences as givens is not likely to be as satisfactory in some settings as one which is augmented by a theory of preference formation.

If human choice behavior is context-sensitive, then one way of getting the context into the theories is through a more careful specification of what is meant by a "set of alternatives." Typically this set is assumed to be simply an "abstract" set with no specific content. Yet we saw earlier in this paper that it was useful to restrict membership in alternative sets to those which are discriminable by the decision-maker. To make such a restriction is to posit a relation between the decision-maker and the alternative set. This rather simple requirement would likely cause problems for spatial theories since there is an implicit assumption that every voter is capable of making infinitely fine discriminations. Yet there is considerable evidence to support

the claim that voters vary considerably in their "level of political information" and consequently in their ability to discriminate alternatives.

Moreover, the formal definition of rationality makes a distinction between a large set of alternatives and the subset actually available in a given choice problem. This subset was termed a "presentation set." The approaches considered in this essay have implicitly assumed that there is agreement between the analyst and the decision-maker as to what constitutes the presentation set. For example, in the presidential election between Nixon (*N*), Humphrey (*H*), and Wallace (*W*), the presentation set would seem to have been {*H*, *N*, *W*}. Consider a person who prefers Wallace to Nixon, Wallace to Humphrey and Nixon to Humphrey. If such a person is rational and is given the presentation set {*H*, *N*, *W*} we would expect *W* to be the choice. However, Farquaharson (1969) and others, have noted that if the person realizes that Wallace has very little chance of winning, rather than "throwing away" a vote on Wallace, it might be reasonable to choose the second most preferred alternative and vote for Nixon. This is termed <u>insincere</u> voting since it involves voting against one's first choice.

People choosing insincerely might be viewed as choosing irrationally with respect to the presentation set {*H*, *N*, *W*}. However, perhaps {*H*, *N*, *W*} is not the presentation set being considered by the chooser. Instead, the set may consist of *H*, *N*, and *W* together with estimates of each candidate's probability of winning. This is roughly the game theoretic tack that Farquaharson (1969) takes. What seems to be needed then is a theory of perception (which can be used to determine what presentation set will be perceived by the chooser) as well as a theory of rational choice (which will determine what choice will be made from the perceived presentation set).

A further difference among alternative sets is whether the alternatives are, relative to some chooser, "simple" or "compound." A simple alternative is one which cannot be broken down into aspects over which the chooser has preferences. His preferences are simply over the alternative. In compound alternatives preferences over the alternatives are arrived at by comparing preferences over the aspects which make up the alternative. As an example, suppose a person prefers Ford to Reagan. If asked why he had such a preference he might reasonably respond that he did not know why - he simply preferred Ford to Reagan. On the other hand, a person might respond by pointing out that he liked some aspects of Ford better than Reagan and some aspects of Reagan better than Ford and that "in balance" he prefers Ford to Reagan. In such a case "Ford" and "Reagan" are labels for the aspects over which the preference is determined. Such compound alternatives could well result in intransitivities (since this is the Arrow problem one level reduced where now the individual is aggregating his own preferences over aspects into a macro-preference). In order to avoid this problem political theorists typically assume that aspects are well behaved in the sense of being composible. Tversky (1972) on the other hand, has proposed an "elimination by aspects" theory of choice which specifically depends upon a person sampling aspects of alternatives and choosing on the basis of this sampling. Such a procedure can produce intransitive choices (though preferences over aspects may be transitive). Tversky's theory has recently been applied to the voting choices in primaries in Williams et al (1976).

At a higher level of gneerality, the work of Allen Newell and Herbert Simon in the area of human information-processing and problem-solving is directly relevant to the development of context-sensitive theories of choice. For example, Simon's well known (though never adequately formalized) notion of

satisficing is an attempt at ". . . the simplification of choice processes . . ." and ". . . is the replacement of maximization with the goal of satisficing; of finding a course of action that is 'good enough . . . It will be seen that the organism that satisfices has no need of . . . a complete and consistent preference ordering over all possible courses of action" (Simon (1957 : 205). In proposing this notion, Simon is paying explicit attention to the costs of being rational. All of the choice theories considered in the previous sections assume that the individual pays no price to be rational; that the cognitive processing capabilities and processing time necessary to make rational choices are "free" goals to the decision-maker. Yet this is clearly not the case. There are, for example, many decisions (e.g., what to wear on a typical morning) which are of such little concern to some of us that it makes no sense to generate a complete set of alternatives and then select form that set on the basis of our preferences. Thus for *decisions where interest is low or the environment* is very complex (and it seems that many political decisions meet both of these criteria) we might not expect to see people act consistent with a maximizing assumption. Riker and Ordeshook (1973:) argue that satisficing is simply utility maximizing over a reduced alternative set. There are, however, important differences. First, in satisficing, choices may depend upon the order of the search. The search will stop when a satisfactory alternative is identified. Which alternative this is may depend upon where the search started. This is not true for maximizing behavior. Choices resulting from maximizing behavior will be independent of the search path. More importantly, maximizing behavior requires that the alternative set be identified prior to choice. Satisficing permits alternatives to be generated as the decision process goes on. Satisficing is, however, not inconsistent with rational choice broadly defined. It simply

focuses our attention on choice as a process rather than choice as an event.

To conclude, axiomatic theories of choice would seem to be a potentially powerful tool in explaining individual political behavior. Indeed the assumptions of some of these theories are basic to many commonly used techniques of scaling and index construction (e.g., see Strand, 1975; Weisberg, 1975). The assumptions themselves are not at issue as much as is the class of political contexts in which specific assumptions apply. Some very preliminary suggestions in this area have been made by Nurmi (1975) and obviously much of the experimental work done by social psychologists (see Kirkpatrick, et al, 1976) is potentially relevant. It still remains for political scientists to develop categorizations and theories of choice behavior which are as relevant to individuals in "political" decision-making environments. Such theories - which I think will have to turn out to be context-sensitive - will likely be of as much potential interest to psychologists and economists as their theories are presently to political scientists.

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A Methodology for the Elictation of Production
Rules for Complex Social Processes*

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A METHODOLOGY FOR THE ELICITATION OF PRODUCTION RULES FOR COMPLEX SOCIAL PROCESSES

In the thirty-three years since Post (1943) first developed the idea of production systems, they have been applied to a wide variety of processes ranging from simple physical systems (Smith, 1972), to well documented psychological processes (Feinbaum,1963; Shortliffe, 1975) to games, such as chess (Newell and Simon, 1972) or poker (Waterman, 1974) to large complex processes about which our information is incomplete, scattered and frequently inconsistent (Coles et al, 1975). These latter types of simulations fall within what Davis and King (1975) call knowledge-base expert systems. The simulation which we have developed in this project unquestionably falls into that category. Its basic characteristic is that the information which is input into the system is heavily dependent on the intuitive knowledge of experts in the general substantive area of the simulation.

In the course of developing this simulation, we have come to the conclusion that there is a pressing need for a rigorous method by which useful and reliable knowledge can be elicited from these experts. Our search of the artificial intelligence/production rule literature, produced little to help us in this area. As Davis and King (op cit) point out, the literature on production system methodologies is very top heavy with discussions of programming style. The information input is assumed to be a matter which the designer of the particular system will be able to supply as a matter of course. Indeed, one finds in most production system projects, the attitude that the substantive information can be input into the system using a highly unstructured "expert opinion" methodology. While we cannot attest to the efficiency of this method, it does appear likely to produce adequate results for well defined, highly structured problems in which

the knowledge base of a single well chosen expert can be assumed sufficient for the purposes of the simulation. For example, one can find an expert chess player who knows enough about the game of chess to describe how to play the game. Unfortunately our experiences in this project have demonstrated to us that the elicitation process is not so simple when the problem is complex with dispersed information and disagreements among experts. For such problems, we have concluded that the elicitation process must be far more rigorous.

Despite the desire for significant rigor, we believe that the ability of production rules to interact well with human logic and judgment should be retained. This means that the heavy emphasis on the elicitation process will lie in the knowledge base accumulated by substantive experts as opposed to the information stored in quantitative or numerical data bases. While the latter certainly can be employed in some aspects of the generation of the production rules, we cannot expect the more traditional social scientific analyses to be predominant in the selection of production rules. Rather, the information sources will be the opinions of acknowledged experts, scholarly books, journal articles and possibly selected observations in the popular media. This article will discuss a process of elicitation directly from functional and area experts when the experts are gathered in a single location. The reader may note that some efficiencies may be realizable by utilizing written material or written communications with the experts. However, until we have the opportunity to experience the more direct methods discussed below, we think that these cost saving short-cuts might well be costly in the long run.

Finally, before we proceed into the details of the methodology, we should strongly emphasize the fact that the elicitation of this information is quite different from the elicitation of opinions a la the survey research people. We are trying to understand how particular social systems work and not how most people

believe they work. We adhere to the belief that there exists a reality against which the correctness of the simulation can be judged.

While the elicitation of subjectively held information does not give the appearance of traditional scientific investigation, many of the same principles and concerns must be addressed. The degrees of freedom problem, which constantly plagues modelers of complex processes exists although in a slightly different form. We cannot, for example, indefinitely alter production rules until the simulation satisfactorily duplicates some aspect of history. There is also a rough equivalent to the inductive vs. deductive alternatives to traditional research. Other analogous questions also exist such as the rules of evidence, methods for removing bias, distinctions between systematic, theoretically based error from random or measurement error. Finally, the quantitatively grounded reader should note that the elicitation procedure we are to describe is the analog of the data fitting process of standard parametric analyses. The expert is essentially attempting to estimate the equivalent of parameters within a general paradigm such that the predictions from the completed model reproduce known reality satisfactorily.

This latter point is particularly important. Systems of production rules can be used for many purposes ranging from listing logically possible responses to given actions, to making decisions concerning which of a set of alternatives will most likely produce desirable results. Our goal lies between these extremes. The simulation being discussed focuses on some "other" actor such as another nation, and lists the major alternatives which its decision makers are likely to consider in response to some excitation and then estimates that which is most likely to be selected. <u>Thus the purpose is to reproduce behavior in a traditional simulation mode</u>. It is not intended to evaluate the desirability of the alternatives in terms of some set of goals.

Some Definitions

Before proceeding into the elicitation procedures, it is necessary to provide a little terminological background. Production rules, as we have used them in this project, have had three elements of importance to the reader of this paper: sentences (s), concepts (c), and production rules (pr). The existing simulation accepts a sentence from the user in a stylized form of English. The computer interprets this into one or more concepts (c). Sets of c's are combined via a production rule to generate an output which may be a direction to one of the substantive modules or an output sentence to the user. In this paper, we will not concern ourselves with the process of translating the user supplied sentences into the concepts nor the translation process back from the outputs to the user. Rather, the elementary unit will be the concept (c).

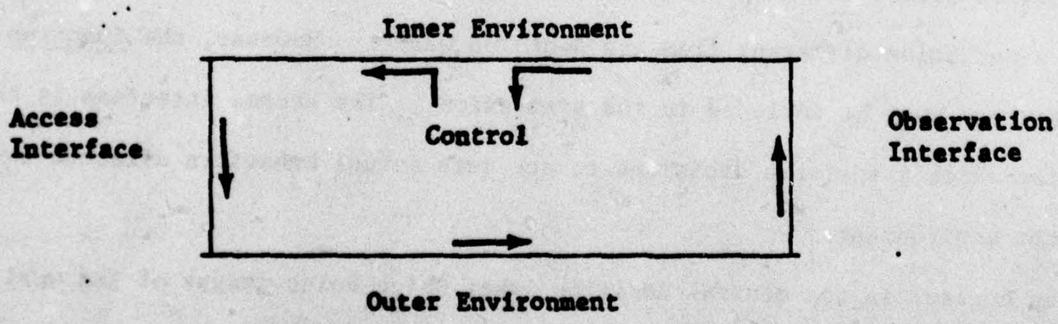
THE PARADIGM PROBLEM

One of the critical decisions which must be made very early in the elicitation process is the determination of the level of structure which will be used to guide the responses of the experts. After some considerable amount of thought, it appears that the question is really one of efficiency. If the simulation is to be successfully developed, there will almost certainly be a stage during which the experts will be forced to formulate a set of ideas within a logically consistent overall paradigm. This may occur at the beginning of the effort or it may take place after there is some consensus about what that paradigm is to look like. It does not seem likely that the developer can simply collect the information from the experts, then formulate the paradigm which is consistent with the and finally develop production rules consistent with the paradigm. The question then becomes whether the developer has a paradigm at the outset about which he feels

sufficiently confident to proceed, anticipating only modest modifications as the simulation begins to take form.

In this paper, we will present a paradigm evolving out of that used for this project.[1] The paradigm is presented primarily as an example to provide the reader with a substantive handle to use to more easily understand the methodology. This example intentionally includes many of the diverse types of problems likely to be faced by the developers of production rule systems. The reader will find that it includes hierarchies of production rules, parametric estimation and steps of production rules of which the direct validating evidence is not likely to be easily obtainable.

At its most basic level, the paradigm used for this example, is grounded in the basic theoretical structure of this project. Since it has been reported several times, we will not present the basic structure and its intellectual predecessors in detail. However, for those who have not familiarized themselves with the rest of the project, we will present it in an abbreviated form. Schematically the overarching paradigm looks like the following:



[1] The paradigm in this paper has expanded considerably from that used as a portion of the total project. The reason for the expansion was to provide a broader overview of the types of production rule difficulties one might experience in developing a complex simulation. For an accurate discussion of the model actually used in the project see Thorson (1976), Anderson (1974).

The model posits the existence of five major elements: the inner and outer environments, the observation and access interfaces and the control module. The inner environment includes all internal forces on the decision process. If the model were a psychological model of individual dynamics, the inner environment would be that which exists at a point of time in the combined physical and mental states of the subject. In our instance, we are dealing with nation states. For then the inner environment includes the nation's internal political forces and the decision-makers' beliefs about the rest of the world. The outer environment includes virtually all that is not contained within the internal environment. At the individual level, this would include all other individuals and the physical surroundings. At the national level, the outer environment would include the attributes and actions of all other nations, international organizations, non-national external actors, multinational corporations and the physical state of all that lies outside the borders of the nation being simulated.

The observation interface is that mechanism which receives all communications from the outer environment and translates them into specific images on the part of the decision makers. In real life, this function would not be completely carried out by a mechanism different from the decision maker. However, the function is necessary and must be included in the simulation. The access interface is that mechanism which transforms decisions to act into actual behaviors directed toward the outer environment.

The control is the central decision maker which holds images of the world and which directs actions intended to resolve those which are unsatisfactory. The control can either issue individual responses to unsatisfactory conditions (e.g. threats, requests, military action) or it may issue directions to the inner

environment to alter some process (e.g. educational programs or investment in oil exploration). In the former case, the response is automatically passed to the outer environment. In the latter, the simulation will alter subsequent economic growth without necessarily passing the information to the outer environment. The control module will be informed of the effect of its decisions as they become known.

The model claims that events occur in the outer environment and are interpreted by the decision-making body at the observation interface. The result of this interpretation is a revision or reinforcement of the decision-makers short-term (or immediate) image of the world. This image is then passed to the control process which either reacts directly to the event or passes instructions to one of the substantive modules (such as the oil module) of the simulation. If a substantive module receives the input it will process it and pass the response through the access interface directly to the outer environment or to the short-term image as appropriate. In its current form, the outer environment makes no decisions. The user will be required to supply the response to the actions passed to it through the access interface. In practical terms, this means that the user will be informed of actions by the simulated nation. He will then have to generate a response. If the simulation were to be totally self generating, there would have to be an equivalent of the observation interface for the outer environment and a decision module for the outer environment. While that would be a desirable feature for the simulation, we see not presently prepared to tackle those problems in detail. The reader should, however, be able to extrapolate from the current discussion, the requirements of such an expansion.

The paradigm, as presented thus far, obviously presents only a skeleton of the form of interactions. In essence, it provides us with a terminology which we can use to further sharpen our ideas before we would being to question the experts.

There are two broad theories which must be employed in the attempt to tighten the paradigm: communication theory and decision theory. Communication theory is required to enable us to translate the events in the outer environment into meaningful interpretations at the observation interface. We treat all events as communications of one sort or the other. The primary question is which of these communications are received at all, and of those what image is generated. The interpretation process includes 1) assigning emphasis to various elements of the communication as a function of the characteristics of the internal and external environment, and 2) misinterpretation. The former is conceptually easy to address. The later is more difficult, because it requires the researcher to make a judgment about the "correctness" of the decision.

Decision theory will be required in the paradigm because the decision module obviously must know how to react to changes in its perceptions of the outer environment. We shall see that the model we have decided upon is a combination of Simon's satisficing model and Ashby's non-purposive adaptation. The decision module must select a set of decisions which satisfactorily addresses the perceived problem and then to select that decision which meets other criteria only remotely linked to the apparent problem. This approach sharply limits the sophisticated comparisons of trade-offs of competing values affected by a single decision.

Communication Theory

It is no secret that scholars have been trying rather diligently to figure out how people interpret the world around them. There is, of course, no question that people can only react to what they perceive. There also seems to be little

doubt that people's method of interpreting the world around them is relatively complex and that they certainly do not interpret identical events identically. Although there have been numerous sets of paradigms with various names such as selective perception, cognitive mapping or cognitive consistency, they generally return to a consistent theme which, while simplistic sounding, is really quite powerful -- people tend to perceive what they expect to perceive (Hochberg, 1964; and Neisser, 1967).

One of the most usable expression of this principle is contained in the general framework of cognitive mapping. John Steinbrunner has done much to clarify the concept to the political science/decision making community in his 1974 book. Others such as Bohnam and Shapiro (1973) and Ole Holsti (1975) have since done further work with the model.

In its essence, the cognitive map concept states that at any point of time, all people have a mental description of the world. This image contains both static and dynamic elements as well as a set of images of the explanatory relationships which link the descriptive elements to each other. The descriptive elements of the cognitive maps are c's. Those elements which form explanatory relationships are much like very complex production rules. For example the Saudi belief that Israel is hostile is simply a concept to be linked with other c's when appropriate. Their belief that hostile entities will frequently attempt to deceive them, provides the basis for a production rule which interprets communications from Israel.

When communications are received which are inconsistent with the cognitive map, something must be done to resolve the inconsistency. In many instances, the message may be discounted as untrue. For example, were Saudi Arabia to

receive a communication from Israeli Prime Minister Rabin declaring that Israel views the Saudis as close and amicable friends sharing the common goal of keeping the Middle East free of Communist influences, the Saudis would probably reject the message as an attempt at deception. An alternative to simply rejecting the message is the substitution of a different meaning. The recipient of the message might, for example, wonder "What are they really saying?". Frequently, for example, one notices experienced observers of foreign affairs "reading between the lines" to interpret verbal communications quite differently from that which one might expert given the explicit content of the message. This occurs in part because the experienced observers have a cognitive map of the other party which is inconsistent with the apparent content of the message. Rather than alter the map, they will interpret the message in a manner which retains the structure of the map. The utility of the alteration of the content of the message is, of course, heavily dependent on the accuracy of the observer's cognitive map. If he tends to be insightful about the other party, the non-obvious interpretation of the message probably conveys more information than would the obvious one.

More frequently than drastically reinterpreting a message, ambiguous communications often require a determination of their meaning. Under these circumstances, the meaning which is most consistent with the previous cognitive map is likely to be the one which will predominate.

The map is, however, not necessarily stable across time. Indeed, in most cases, our images of the world around us are constantly experiencing relatively minor changes although in some instances we actually make drastic reinterpretations of the world. Whether large or small, these changes can have profound implications because the same communication which at one time in the past was given a particular

meaning will now be given a different meaning. Evidence of this sort of change can be seen in the American public from the early 1960's to the mid-1970's. Early in this time period it could be argued there was a more or less general cognitive map that assumed that the utterances of heads of state were truthful. By the mid-1970's there appears to be a belief that if the speaker's self-interest is at stake, he will not tell the truth. This cognitive map would create a situation in which a whole class of communications, which at one time transmitted legitimate information, would now be ignored. Similarly the cognitive maps of the Arab nations seem to have changed dramatically to the short period from 1965 to 1975.

There are however some evidences that cognitive maps can be quite stable. The now famous Holsti study of John Foster Dulles' attitudes (Holsti, 1963) toward the Soviets is a fine example. Regardless of what the Soviets did to the United States, Dulles interpreted the communication as an indication of hostility. If the Soviets appeared to be conciliatory, Dulles assumed that this was evidence of their treachery. If they were overtly hostile, Dulles argued that they were showing their true beliefs.

For this report, we will operate under the assumption that some aspects of decision-makers' cognitive maps are changeable under any of three conditions:

1) Catastrophic appearance of undeniable evidence that some element of the cognitive map is incorrect (such as a military attack when one believed that it would not occur).

2) Repeated ambiguous or questionable communications which appear to be inconsistent with the map.

3) A change in the power structure of the decision making body such that the new power elite holds a different cognitive map than the old elite (only relevant if one is modeling a <u>body</u> of decision-makers).

Catastrophic Change

This particular type of change poses little difficulty to the type of simulation we are discussing. In these instances the result of the communication is obvious: the appearance of a major objective event inconsistent with the existing map requires a change in the map. The stability at significant elements of the map must be maintained. This type of communication is, however, quite infrequent. The true surprise attack would be a good example of such a situation. Here, the decision elite of one nation would believe that a particular Nation was not likely to attack. When the attack occurs, it becomes virtually impossible for the decision-making elite to deny the fact of its existence, or to otherwise reconcile it with the belief that an attack is unlikely.

In recent history, there are a few instances which would probably fit this criteria. Pearl Harbor, of course, is the most obvious. For large numbers of Americans, the launching of the first Sputnik certainly produced immediate and drastic revisions of the attitudes about Soviet technical capability. The initial Nixon/Kissinger forray into the PRC would probably also fit this category. Certainly a few others could be listed, but the point is that the occurrence of these types of changes in the cognitive maps is unusual, and not one which need require a great deal of effort in the development of the simulation's production rules. Simply, for that category of event, the map is immediately revised to fit the new information. The new information is taken at face value.

Repeated Inconsistencies

More frequent than the instance described above is the occasionally repeated instance of some observation which is moderately inconsistent with the cognitive map. For example, old friends may occasionally do things to you that you do not appreciate, nations thought to be enemies act friendly, or national leaders fail

to act in their own best interest when we thought that they would. Under most circumstances, individual instances of these apparent anomolies would be rejected through the use of any of a number of mechanisms such as analogies, wishful thinking, inferences of impossibility, and negative images.[2] It is clear that people have powerful tools to enable them to keep their cognitive map unchanged. However, we know that people do change their minds about the world around them. A simple examination of the apparent image the U.S. holds of many elements of the international environment would indicate that there were some dramatic shifts in the period from the mid-sixties to the mid-seventies. Attitudes toward the Soviet Union softened considerably then hardened by a smaller amount. The attitude toward the Arabs and Israelis shifted from unquestionably pro-Israel to a more evenly moderated position. Furthermore, whereas the U.S. had previously considered the Arabs to be weak and disorganized, they are now seen as a powerful and reasonably well organized world force. In other areas, out attitude toward the PRC no longer reflects the illusion that they are simply a puppet of the Soviet Union. Japan, once thought to be a strongly pro-American ally is now viewed as somewhat questionable. And, the belief that the U.S. military can easily defeat anyone except the Soviet Union has been rudely shaken by the Viet-Nam experience.

So it is apparent that the cognitive map is not constant despite the impediments to change. Indeed, it would not seem reasonable to assume that stability of the map is a good approximation of reality. Were it so, the substance of the rules would be more obviously apparent then we have found them because identical inputs would be likely to generate identical outputs. Also, they would be structurally simpler, because there would not be the need to have the production rules contain within them something resembling learning functions.

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[2]For a much more detailed discussion see Steinbrunner, 1974, pp. 114-121.

Let us assume that decision makers do gradually change their images of the world on occasions. These changes seem to develop from repeated information requiring the decision maker to reject or alter the content of the communications. However, despite the fact that we know quite a lot about the factors which make people resistant to changes in their mental images, we have relatively little knowledge of what parameters permit change.[3] To the extent that we do understand the process, we know that the likelihood of a segment of the map to be changed is inversely related to the length of time that it has existed as a part of the map, the frequency of its use, the relative amount of information supporting it and the peripheral support. For a given individual or collection of individuals, the receptivity to change is a function of the relative amounts of information held in memory supporting the map and the amount of information received which contradicts it.[4] This concept is complicated by the fact that supporting information is generally afforded greater importance than is contradicting information. This derives from the well-known process of maintaining a given stimulus-response pattern with only intermittent reinforcement.

To operationalize this concept, let us imagine that at time t_0 the decision maker has a given element in his cognitive map with a mixture of supporting and non-supporting background evidence resulting in overall support of the concept at the level η. For example, the element may be a Saudi image that the United States will maintain an even handed policy toward the Arabs and Israelis. Another element might be the belief that the Israelis are deeply anti-Arab and likely to give ground to the Arabs only when forced to do so. Intuitively, we would believe that the Saudis would hold the latter belief considerably more strongly

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[3] For the best discussion of this process see Cohn, 1964, or Hovland, Lumsdaine and Sheffield, 1949.

[4] Steinbrunner, op cit.

than the former. Let us call the firmness of the element of the map its <u>hardness</u> designated by η. "η" is a function of the length of time the element has existed in the map, the number of supporting communications, the ratio of supporting communications to contradicting communications and the extent to which it exists within a number of other supporting elements of the map. The latter factor would apply, for example, to the Saudi belief that the United States will act even handedly in the Middle East. In addition to the direct supporting evidence, the United States is known to oppose Soviet involvement in the region and the United States is known to be dependent on the Arab oil. Thus, to alter the initial belief, would require some resolution of the two other supporting elements of the map.

Let us now imagine that a piece of information is received which would indicate that the U.S. may not act even handedly in the region. Let us designate the strength of this signal as ι.

If η and ι are measured along identical scales, the map will be retained as long as $\eta<\iota$. Then, the message will be interpreted in a manner consistent with the map. However, η will be decreased by an amount proportional to $\frac{1}{\eta}$. Thus as repeated messages are received contradicting the initial image, η will decrease at an increasing rate. We can see that we have a functional relationship: $\frac{d\eta}{d\iota} = -f(\frac{1}{\eta})$ (1).

Alternatively, as supporting messages are received, the map is hardened proportionately with η. Thus, for supporting messages: $\frac{d\eta}{d\iota} = f(\iota x \eta)$ (2). In the simplest case, we would expect that the functional relationships would be more than the non-varying parameters ζ and ν respectively. These would obviously transform equations "1" and "2" into

$$\frac{d\eta}{d\iota} = \zeta(\frac{1}{\eta}) \quad (3)$$

and

$$\frac{d\eta}{d\iota} = \nu x_{\iota} x \eta \quad (4)$$

For those individuals who tend to be resistant to change "ζ" would tend to be small. Similarly, those individuals who tend to be excessively influenced by their own successes would tend to have large values of "ν."

Recalling that any change in the cognitive map may require changes in other supporting elements of the map, the developer of a model such as this may wish to introduce this compounding influence into the model. If this were desired, we would require simply the inclusion of the subscript m representing the m^{th} element of the map. Equations 3 and 4 then become the more complete equations:

$$\frac{\partial\eta_m}{\partial\iota} = \zeta \prod_{m=1}^{m} (\frac{1}{\eta_m}) \quad (5)$$

and

$$\frac{\partial\eta_m}{\partial i} = \zeta \prod_{m=1}^{m} ({}_{\iota}x\eta_m) \quad (6)$$

From these equations it is easily seen that η can be incremented or decremented as appropriate. When its value falls to less than zero, the concept will be extinguished, and the new contradicting one will be substituted in its place.

Change in the Power Structure

When one is dealing with group decision-making, the impact of either changing the group or of changing the weights of the opinions of the group members can be quite important. The current simulation does not have, at present, a domestic politics module and therefore cannot deal with these types of phenomena automatically.

Indeed, at present, there is no way that the existing simulation can handle changes in power structures at all. Currently, the user must manually alter segments of the cognitive map if he believes a power shift were to occur. This would require that he define the new map and insert it either from the terminal, if the revision is no more than a replacement of elements currently available to the simulation or through a programming change if the changes are to be more drastic.

The three basic types of changes in the cognitive map described above (catastrophic change, repeated inconsistencies and change in power structure) reflect three basic types of production rules. The first is the simplest. Here the system identifies a concept as indicating a catastrophic change. This is probably done most easily by matching the change against a list of potential catastrophic changes. There is then a simple production rule which says to change any c's which are inconsistent with the implications of the catastrophy and then to proceed to act in accordance with other production rules which will be invoked by the change in the c's.

The third possibility shows that there must be provisions in the simulation for missing production rules. We are a very long way from realizing a nearly complete simulation. If sophisticated users are to be able to interact intelligently with the simulation, there must be some mechanism to permit them to manually alter some elements of the system while it is running.

The second type of change is an example of one of the more complex sets of production rules. The system will identify a concept which is inconsistent with another concept. This then invokes a production rule which does not alter either of these two concepts but rather alters another concept, λ, the strength of the concept originally held in the memory. Finally, there is a production

rule which keeps track of the λ's and handles the replacement process when a λ falls to a value less than zero. After all of this occurs, the decision making production rules are invoked.

Decision Processes

There are numerous models describing how people do or should make decisions. This is, however, not the place for a review of these models. We have selected for this paradigm, a combination of the models proposed by Ross Ashby (1952) in his discussions of non-purposive adaptation and Herbert Simon (1957) with his "satisficing" principle. Ashby generally argues that living organisms learn less through a deliberate, purposive, cognitive process than through the variables of concern with behavioral adjustments when the levels are unsatisfactory along any of them. The process in his model is closer to random searching than it is to the well reasoned optimizing models posited by many economists. The amount of randomness is a function of the level of experience in dealing with a particular type of problem. An experienced automobile driver, for example, does not react randomly to the perception of an erratic driver headed the other way. The novice, on the other hand, might well panic in such a situation and engage in a search for alternatives which would have many characteristics of randomness.

We will alter Ashby's model by assuming that there are two restrictions on the choice of the behavior: familiarity and "satisficing." We will assume that, all other conditions having been met, decision makers will select that alternative most familiar to him. Thus we might expect to see a generalized behavior pattern appearing across a broad range of stimuli.

The other constraint is Simon's well known "satisficing" principle. It is really a version of weak nationality. Rather than searching through alternatives to find that which provides the highest level of utility across

several dimensions of value, Simon argues that individuals will search through their alternatives until they find one which is expected to give satisfactory results. At that point, they will end their search and act upon it. While these two models discount some of the conscious maximizing behavior used by some individuals some of the time, they (the models) do appear to have captured a large element of the decision making process of most people.

If these two models are combined, the resulting model argues that the perception of the world stimulates a small number of sensors which in essence describe the fit between the state of the world and the goals of the decision-making body. If one or more of these indicate an unsatisfactory level, a search for alternative decisions will be begun. Elements of the memory will serve as filters permitting consideration of only those which logically might be expected to raise the unsatisfactory initiating condition(s) to the satisfactory level(s). For those situations in which there are no serious and immediate trade off questions, that alternative which has been used successfully most frequently will be chosen. The simulation will then monitor the response to the approach and judge it as satisfactory or unsatisfactory. If the judgment is the former, the method will gain increased stature as a desirable option in future problems. If unsatisfactory, the method will be given marks against it. Again relying on the principle of intermittent rewards, a success should count more in favor of a method than a failure should count against it. One can, of course, see strong bureaucratic reasons why success would be more apparent than failure. In any event, the result of this procedure is to perpetuate existing behavior patterns if they have so much as a 50-50 chance of success on any given trial. This would not be inconsistent with the apparent tendency of nations

(people) to find themselves in fairly consistent patterns of behaviors (i.e., _ruts).

One of the central elements upon which the simulation depends is the option selector. We know that human beings when confronted with a problem consider only a very small set of the possible responses.[5] This is clearly necessary because of the inefficiencies involved in making even a cursory evaluation of totally unreasonable options. While we are not certain of the methods by which humans organize this filtering process, the computer must do it through a series of hierarchial categories. The Soviet mobilization in the 1973 Arab-Israeli conflict for example, may have been categorized as: major power, probably not including strategic nuclear weapons, probably restricted to main force conventional combat with the possibility of tactical nuclear weapons. This description basically delimits the range of possible responses. It is important, and difficult, for the computer to accurately reproduce the set of options which, in "reality," are considered by decision-makers. Furthermore, this must be done in a general system which will construct the alternatives from primitive segments rather than from a simple look-up list.

Unfortunately, we do not see any methodological tricks available to help the developer in this problem. The success will be largely dependent on the abilities of the developer and experts in conceptualizing the problem into useful generalized building blocks. There are, however, two factors which must be recognized: the categories are not very neat. There is considerable overlap between the various elements. Any given combination of short term images is

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[5] Newell and Simon, <u>Human Problem Solving</u>, pp. 300-303.

likely to have some factors in common with a variety of broad categories of problems. The concept of Fuzzy Sets (cf Zadeh, 1965-1974) may be a useful tool in this categorization problem. Secondly, the developer and the experts do have the luxury of testing the categorization scheme for *plausibility* by assuming a wide variety of concepts (c's). This gives them the possibility of iterating to a set of categories which appears to reproduce reality fairly effectively.

The problem of the success/failure rate and its impact on the ultimate choice of a decision is quite similar to the changes in the cognitive maps we discussed above. Under the simplifing assumption that successes or failures are correctly perceived, we are obviously attempting to reinforce or extinguish a behavioral pattern having some previously established strength in the mind of the decision makers. As previously described, the strength of the belief is designated ι, the extinguishing constant is η and the reinforcing constant is ν. These factors are functionally related to each other in the manner described in equations 1-6.

A more difficult task is the evaluation of the success or failure of a given set of actions. Unless multiple valued outcomes of a decision can be accurately measured and acceptably reduced to common units, such as dollars or utilities, the evaluator is faced with severe comparability problems. How, for example would he reproduce the evaluation system of a composite decision maker which had observed ambiguously measured success along two criteria and had measured failure equally ambiguously along two others? The normal approach is to compute weighted averages along several dimensions of value and to sum them for the total measure of success. While almost unquestionably the most reasonable means of making an evaluation of a multidimensioned phenomenon, there is little to lead us to expect that human beings engage in anything very

close to this sort of mechanisms. And, remember, we are attempting to reproduce human behavior.

The question is not easy, and is, in fact, probably that about which we have the least confidence in the model. Nonetheless, we assume that not only are evaluations multidimensioned but also dual-purposed. While initially appearing to further complicate the mess, it does give us a capability to divide the evaluation task into two segments. The first is the gross overall evaluation which is used in the selection process for future decisions. The second is a detailed evaluation used in structuring more subtle aspects of the subsequent decisions.

The overall evaluation is made along only one dimension -- that which instigated the most recent decision. If, for example, the U.S. made an offer to sell Pershing missiles to Israel, this would create a response by the Arabs. The model will evaluate aggregate success or failure simply on the basis of whether or not the U.S. rescinded its offer or made an equivalent offer to the Arabs. The univariate success will be determined by the parameters ι, η and ν. Any other economic or political costs would not be included in the gross evaluation. They would be kept in memory, however, and were the situation to arise again and the same response be selected, any unsatisfactory costs in the memory would automatically invoke the trade off analysis to be described below. This would require a more detailed analysis of any other possible options for similar secondary side effects.

A disturbing aspect of the decision criteria described above is its insensitivity to trade offs. Admittedly, there is unquestioned evidence that people do avoid the reality of trade offs to a surprising extent (cf Steinbrunner op cit, pp. 112-125). Nonetheless, the assumption that people never engage in conscious comparisons of the trade offs of various alternative decision strategies

would be far too strong. At present, we do not have the capability of providing the simulation with a sophisticated means of determining when decision makers will repress the "existence" of a trade off situation (recognizing that we as analysts do not hold unquestioned knowledge of whether a trade off situation "really exists"). For simplicity, we will simply assert that trade offs are considered only when they cannot be immediately avoided.[6] If, for example, a large purchase is to be made, it is unavoidable that the decision maker must consider the impact of the expenditure on the economy. Does he have the money at all? Must it be taken from other important projects? Similarly, if the decision maker is interacting with one or both of two enemies, it is difficult to avoid noticing the possibility that actions taken favorable to one will be viewed as unfavorable to the other. At the present time, we will instruct the simulation to consider the possibility of trade offs only when the primary alternative contains an explicit cost which would occur with high probability and within a short time frame.

When trade offs are considered, decision makers will still employ the satisficing principle. The principle will be employed sequentially with the requirement that a satisfactory level be anticipated on the highest priority goals before lesser goals can be considered. At no time will the decision maker select an alternative which will provide him with a lower priority goal at the risk of sacrificing a higher priority one. If there exists more than one strategy expected to give satisfactory performance on a high priority goal they will all be compared on the next most important goal. Of those which

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[6] We assume that a memory of past costs associated with a decision will foreclose avoidance at the trade off.

appear to satisfy both goals, that which has been used successfully most frequently will be selected. If there still remains an explicit trade off to be made, the process will be repeated with the third highest priority goal, etc. This method has been used successfully by Bohnam and Shapiro (1978).

If the system is forced to recognize the fact that it has been faced with a trade off situation and that a particular goal has been placed in jeopardy, we assume it will be particularly sensitive to the unfavorable consequences of its actions and will begin to search for alternatives to alleviate them. This arises as a result of an unwillingness to recognize the zero sum characteristics of the previous decisions. For example, if a decision were made to increase defense efforts, one might believe that the effort would instigate additional defense efforts by one's enemies. In order to prohibit this eventuality, it is easy to imagine diplomatic or economic efforts intended to encourage the enemy to hold expenditures at a constant level while the initiator was increasing his. In short, the model assumes that it is only with great reluctance that people act as though they really believed that you cannot have both guns and butter. The behavioral response will be a series of "tacked on fixes" to previously generated problems.

The satisficing principle tends to encourage the likelihood that individuals will attempt to reach satisfactory levels even along basically zero sum dimensions. Since there is considerable ambiguity about the "satisfactory" level of success, people can lower their expectations in order to preserve the belief that they can have satisfaction along the multiple dimensions. For the time being, however, we have no mechanisms for decreasing minimum goals. Therefore, that aspect of the paradigm remains incomplete.

Summarizing the paradigm as it stands currently, we assume that a communication in the decision maker's outer environment, when linked with the contextual information, will generate a perception by the decision maker. We assume that there are numerous possible interpretations of the communication. The one which is selected will be that which is most consistent with the existing cognitive map. If the overt content of the message requires alteration to bring it into consistency with the map, this will be done, but the strength of that element of the map will be reduced. Successive messages inconsistent with the map will tend to alter element of the map which is being affected.

Once a perception is generated, a reacting decision will be made. The decision will initially based on the comparison of the state of the world relative to the goals of the decision maker. If there is a discrepancy, an attempt will be made to achieve a minimally satisfactory solution. Of the alternatives which will give the decision maker the expectation of satisfaction, the one actually selected will be that with which he is most familiar.. If value trade offs must be made, they will be made only with great reluctance and will generally produce a search for alternatives which will provide satisfaction along all threatened dimensions. Even if one value dimension must be sacrificed, there will be a subsequent search for alternatives to attempt to recover the expected (or observed) loss.

Translating these last few pages into production system terminology is a bit more difficult than was the case for the perceptions. The decision process is always invoked by an unsatisfactory condition along one or more of the c's. This condition will always be passed to the decision-making production rules from the perception generating production rules. Recalling the use of the satisficing principle, minimum satisfactory conditions must be attached to those concepts

where they are appropriate. (Most concepts will not, of course, have satisfaction conditions attached to them.) In addition, those with satisfaction ratings must have at least ordinal priorities attached. This permits the system to choose the order in which it approaches a problem. Thus when a set of c's are changed, the system must search for unsatisfactory conditions and order them by priority. Having done this, there must exist a set of production rules which generate the set of logically possible responses to the unsatisfactory conditions. As we discussed, this will be done on a concept by concept basis without consideration for trade offs except where they are unavoidable. Even such a limited requirement is not easy to handle. It requires that a set of production rules be developed to anticipate the immediate costs of courses of action. These production rules have the capability of doing some of the most interesting actions of the simulation. They initially receive their cost information from the developer but during the simulation, they will "learn" additional costs as the user supplies responses to the simulation's decisions. This is accomplished by encoding within these rules a record of the unsatisfactory levels in the round of activities immediately following the decision to act. If the result of an action intended to raise C_i to satisfactory levels is the decline of C_j to unsatisfactory levels, the cost will be recorded and used in subsequent decisions.

In addition to those production rules predicting the <u>costs</u> of courses of action, there must be a set of production rules anticipating the <u>workability</u> of the solution. Recall that the model states that the decision makers will examine the logically possible alternatives and choose that which has been used most often most successfully in similar situations. This process has two complicating factors: look ahead time and number of factors to consider. When

decision makers consider the situation to which they are responding, a part of that situation is the future. Unfortunately, that would complicate an already complex simulation. Were it to be done, it would essentially require the development of a mirror image simulation to be developed to handle the outer environment. For the time being, however, we will suggest omitting that option.

The other complicating factor cannot be so easily dismissed. Even though we have made the simplifying assumption that we will normally deal with only one unsatisfactory "c" at a time, the circumstances surrounding that situation still must be considered. This is best accomplished by attaching to the courses of action, a set of minimum requirements for action. This means that once a course of action has been provisionally selected, there must be a check to determine if other c's are configured in a manner which gives the course of action a reasonable chance of being workable. If so, the action is implemented. If not, the next course of action is selected. If none of the prospective courses of action are workable, an attempt will be made to alter the c's. If there are still no workable solutions, the user should be made aware of the problem and given the opportunity to select a course of action. The reader should not, however, make too much of this limitation. In the large majority of the cases, there will be at least one workable solution. Remember that the limitation is not severe. The most widely used course of action simply must be workable. There is no requirement of success.

Once the decision is made, the system keeps track of the satisfaction scores through as many time periods as the developor chooses. Evaluations of the success or failure are made on the basis of the direction of change of the affected

variable and the highest priority other concepts. The relative weights of success or failure is discussed above. This is admittedly a primitive form of evaluation, but it can be improved at a later date if desirable. Methodologically, the reader should note that here we have a set of production rules which primarily engage in searching routines. Since the changes in the evaluation scores will determine the appearance of learning, the production rules themselves do not change during the course of the simulation. The output from a given user input may differ from one time to the next, but this is a result of systematic changes in the data on which they operate.

ELICITING THE RULES

While the paradigm presented above is not particularly complex, it should be apparent that potential developers of a totally numerical model would find themselves faced with a very difficult task of data collection and analysis. Indeed, there is a real question whether it would be possible to gather data of sufficient quality to provide a reasonable test of such a model. While some elements appear amenable to these analyses, many would appear to be extraordinarily difficult to subject to any testing which would satisfy a potential user. Herein lies the strength of the production system format. The paradigm is structured such that much of the information probably exists somewhere in the brains of those experts who have made it their business across the years to obtain and synthesize a wealth of knowledge about the decisions to be simulated.

The elicitation of the production rules, however, is not something to be taken lightly. As the reader will see, we are suggesting that it will be necessary to spend many hours with the substantive experts. Furthermore, there will be numerous iterations of segments of the model along with tests against objective observations of past behaviors.

The Experts

Once the paradigm is developed, the selection of the experts to be used to provide the production rules is a significant task to be undertaken with care. It is they, after all, who are to provide the basic knowledge upon which the simulation is to be constructed. The experts should be selected along two criteria: *substantive area of knowledge* and *suitability to the production rule elicitation process.* Substantively, the developer of the simulation should examine the paradigm to determine the bits of knowledge he needs. It would seem reasonable to include at least two representatives from each of the area specialties. Multiple experts per army should permit informed dialogue which should tend to improve the production rules. Clearly there is a trade off between the improved information provided by multiple experts against the disadvantages of the mass chaos or over organization which often accompanies large workshops of experts. The number of experts is, of course, also a function of the time and budget of the project.

Another of the substantive concerns is a need for consistency with the basic paradigm. While there is a good reason to obtain as diverse a set of opinions as possible while developing the paradigm, once developed, the researchers cannot afford to spend additional endless hours debating with the experts over its validity. In our example, we would not select someone who believed that the perceptual process should be bypassed in modeling decisions nor would we choose someone who was a strong adherent to the principle of value maximizing.

As important as the number and knowledge base of the experts is their ability to give time to the effort. If the simulation is even a moderately ambitious project, as was the current effort, the experts must recognize that they will be needed for extensive periods of time. Indeed the total number of

person-hours of experts' time may well rival that which has traditionally been associated with graduate students in aggregate data collection. Thus it should be emphasized that we are not talking about a matter of two to three days per person. There will in all probability be several iterations of the rules until a satisfactory version is finally ready for distribution. A corollary to this requirement is the need to provide some reimbursement to the experts. Academics of course can usually be purchased via consulting fees. Experts within the government could well be extremely valuable but financial reimbursements are normally outside the law. In addition, it is often extraordinarily difficult to obtain the release of those individuals who would be needed the most. While some bureaucrats could be obtained for limited assistance with ordinary means, the procedures would have to obtain the organizational support equivalent to that required for a net assessment to realize any substantial assistance. Fortunately, many of the Washington based research corporations have on their staffs very knowledgeable former government employees. They could serve as alternatives to the current policy operators through consultation or sub-contracting arrangements.

Summaring developers of such a system probably would be able to obtain the required help of experts, but even obtaining this assistance will be a task of some significance.

Data

It is not enough, however, simply to have a group of acknowledged experts. One of the major differences between the method we are suggesting and other expert based systems is that we will be employing more rigorous methods of testing their assertions. We will make extensive use of detailed verbal chronologies of the recent behavior of the persons or groups to be simulated.

These chronologies can be obtained from newpapers, journals (such as the Mid-East Journal), published chronologies of historical events (e.g. Monsoor (1973), and computerized chronologies such as uncoded WEIS or the Oak Ridge collection. These chronologies will be called data. Any references to data from this point on in the report will be synonomous with the chronologies either in their raw or coded forms.

In brief, the methodology calls for the iterative testing of segments of the production rules against the chronologies until a satisfactory match can be obtained. Since the developer will not know ahead of time what substance will be contained in the production rules, the initial collection procedures should emphasize breadth and volume. This is not as monumental a data gathering effort as might be imagined because there is only minimal processing of the data. Initially, there will be no need to go through expensive and tedious data coding processes such as WEIS, CREON, etc.

At this stage in the development of the methodology, it is difficult to determine how much data will be required except that the demands are certain to be quite severe for all but the simplest simulations. As strictly a ball park estimate, we would estimate that for a test of the paradigm discussed above, one hundred thousand words of relevant chronologies would be needed.

The testing process will be organized hierarchically by "class of production rule." A class of production rule is a set which, as a group receives concepts from the user or other production rules, operates on them and passes them to another set. In our example, we have three classes of production rules: setting of the cognitive map, setting of immediate perceptions, and making of decisions. The structure of the cognitive map will control the perception mechanism. The

perception mechanism in turn passes information to the decision mechanism so that it can operate. Other paradigms may differ in their complexity ranging from very simple S-R models to highly elaborate rational choice models with sophisticated trade off evaluations. The former would have only one class of production rule. The latter could have virtually unlimited classes.

Once these classes have been identified by the developer, the data should be categorized according to its ability to lend inferences to the correctness of predictions of the various classes of the production rules. This will simplify the task of retrieving this information when the testing phases begins. Additionally, it may provide an indication of those areas where the data collection has been inadequate.

It is important that the narratives be as complete as possible. In most instances, there will be a need to make subjective judgements of the degree of fit between the simulation and the observed events. Thus the greater the detail, the more useful will be the evaluation. Because the simulation makes statements about portions of the process unavailable to direct observation (e.g. perceptions), the data should contain enough information to permit subjective interpolations between the points of observation. For example, even though we might not have a piece of hard data indicating that the Saudi king was angered by a given U.S. action, there may well be enough information to permit the inference that "He must have been angry to have done what he did."

Finally, many of the elements of the model may be sufficiently generalizable that chronologies from other, perhaps, similar, national actors may be acceptable substitutions. This would permit the expansion of the data base for more extensive testing.[7]

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[7]We would suggest that the reader reread the data section after having read the elicitation section. Unfortunately, it is necessary to understand the elicitation process before the data section makes much sense. Alternatively, it

The Elicitation Procedure

Once these preparations have been made, the developers are ready to begin the task of eliciting the production rules from the experts whom he has chosen. From the data preparation stage, he will have delineated the classes of production rules and ordered them hierarchically.

The production rules will be generated sequentially from the top of the hierarchy to the lowest. At each class, the developer must first select the concepts which will be the starting point of the class. This will be a large and critical stage for the top of the hierarchy for it will receive the direct inputs from the user. The class of c's which start the process will be one of the primary strengths or weaknesses of any of these types of simulations. These will have to fit the format of the paradigm, but can take as broad a substantive range as the experts wish to supply. Here there will be constant questions of categorization schemes. The developer will be torn by the desire to have an elegant, parsimonious, general simulation, but one which also contains extensive detail. There will, however, have to be some categorization scheme, since it is not likely that the developer and experts would want to list all possible concepts.

Once the input c's are assembled and properly categorized, the production rules for that class must be created. Here again, the developer will have to interact extensively with the experts to develop categories of inputs and categories of production rules. This is necessary to prevent a tendency to develop a production rule which predicts a single specific output if invoked by a specific permutation of c's. Instead, each production rule should be

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is necessary to understand the data before the elicitation and testing processes can be understood. Thus we suggest that the reader read the sections once to generally get an overview and then again to understand how the process should work.

general enough to permit the processing of any of a set of concepts. This is difficult, but necessary if the simulation is to be applicable to a diverse set of problems (Feigenbaum, 1971).

For all of the classes of production rules, the output will be a set of concepts. For all except the last class, these concepts will be the input to the subsequent class. Thus in working on the subsequent class, a close examination of the required input concepts will provide a partial test of the adequacy of the previous class to supply them.

It should be apparent that the generality requirement is quite important to the success of the simulation. If the simulation becomes weighted down with detail, it will be both inefficient and probably incapable of accepting a new permutation of concepts which a user may choose to input into the system. A second major problem will be the resolution of the disagreements between the experts.

Generality Requirements

Probably the most difficult task in eliciting information from substantive experts is to direct them to useful generalities. There seems to be a strong tendency among experts to recite anecdotes. For our purposes anecdotal evidence is useful only if it is an input to a useful generality. The simulation, it must be remembered, should be capable of operating across a wide variety of combinations of factors even though the experts may never have directly observed many of the particular combinations. This can only be done if the simulation is a true set of principles generalizable across a reasonable spectrum of possible circumstances. To a large degree, the paradigm will provide the most useful aid

in maintaining the generality of the simulation. The paradigm is a broad but general statement about reality. It is, or should be, a logical sequence leading from the occurrence of some instigating activity through perception to decision into which the observations of the experts fill the missing holes. Thus in our example, the developer should always be aware that the third class of rules is intended more to describe <u>how</u> decisions are made rather than which previous decisions were made. By rigidly forcing the experts into the questions logically required by the modules of production rules the generality problem should be manageable. Clearly, it is here that the strength or weakness of the simulation will be shown. A strong paradigm will approach an ideal of simply asking the experts to fill in the blanks. The questions should be apparent from the paradigm and the initial set of concepts. A weak paradigm would give the experts the freedom to talk rather aimlessly about the subject at hand. While the ideal is not achievable in the near future, a strong explicit paradigm will help tremendously in developing a general set of production rules.

One of the methods used by Newell and Simon (1974) in examining the means by which individuals solved crypto-arithmetic and logic problems would seem to have some utility in eliciting generalized pr's. The developer might for example ask the experts to describe the cognitive maps of the Iranians at a series of periods of time and the reasons that they (the Iranians) operated from those maps. By tape recording the verbal responses, the developers should obtain a wealth of basic causative statements' which can be broken down into production rule format. Many of these causative statements will be formulated in overly specific terms. As the developer collects the series of specifics as stated by the various experts in their exercises, it will be up to him to arrange them

in some meaningful categorizations. Thus for example, he might find a series of causative statements which would be categorized as dealing with defensive, military-oriented cognitive maps. Even these may be organized into clusters dealing with the U.S. and NATO, Soviet bloc, Arab radicals and Arab conservatives. Once categorized, the developer could reformulate them into statements directly translatable into production rules. Having done this, he should reconvene the experts and decide if they agree with the categorizations and the subsequent genralizations. If there is agreement, the statements should be transformed into production rules and tested.

If there are minor disagreements, the collectivity of experts may be able to easily resolve them and immediately suggest new or revised rules. If the rules are widely thought to be far too simplistic, there should be a repetition of the initial questioning process. If there are outright disagreements between the experts, the following procedure should be followed.

Disagreements Between Experts

It has to be assumed that there will be a large number of disagreements between the experts. This is, in fact, a major disadvantage to the method. The ultimate method available to the developer of a model of this type is the empirical test against the chronologies. The developer will rapidly become aware, however, that the chronologies are very scarce resources to be used as sparingly as possible. Thus there are significant reasons to seek to resolve the differences of opinion as early as possible. The developer has a number of possible selection procedures available to him. Initially, of course, the disagreements can be pointed out to their respective authors with the expectation that one or more of them may immediately recognize an error. Secondly, the developer should examine all the causative statements of the disputing experts

for internal inconsistencies. If a given expert has provided a causal explanation which is inconsistent with other causal explanations he has given, the resolution may solve the differences which he has with the other experts. Yet another alternative is to formulate the causal statements into the set of production rules and either manually or on the computer, subject them to sensitivity testing. If one tends to produce unreasonable responses to reasonable inputs, it would have to be held in question. Finally, if all of these methods fail to resolve the controversy, there exist the set of convergence methods such as Delphi. If used with great care these methods can obtain satisfactory solutions. They have the disadvantages of being expensive to employ and of reducing the chances that an unusual but superior solution will rise to the top. Nonetheless there are circumstances when these disadvantages are outweighed by the need for some resolution of the difficulties.

It can be expected that these procedures should produce for each set of production rules a decision about which of the various disagreements appears to be best. We should expect, however, that in some instances, these decisions may be based on very flimsy evidence. That is, we must anticipate that even after this extensive process of resolving differences, we will still have reason to believe that some of the rejected alternatives are quite plausible. A list of these should be stored (possibly on the computer in production rule format) as replacement production rules when early iterations of the simulation produce predictions which are inconsistent with the chronologies.

<u>Parameter Estimation</u>

One of the most difficult portions of the model development could be the estimation of the parameters ι, η and ν. Those who have attempted to elicit numeric parameters from experts know that it is extraordinarily difficult. Substantive experts notably have considerable difficulty with questions of the

quantification of ambiguous concepts such as these. Fortunately, it can be argued that these parameters are constructs more of personality types and their interactions than of nations or specific sets of individuals. Thus it should be possible to determine these values experimentally if the subjects are chosen to be representative of the decision making group being simulated. It should be remembered that since these are general concepts applying to extinguishing and reinforcement of beliefs, results may be transferable from one group of individuals to another.[8]

Testing and Validation

At the outset, we should recognize that this type of system should never exist in its final and static form. Hopefully, users will continually make inputs to improve it even after it is finally determined that it is worthy of distribution. Thus it is expected that these types of models will proceed through an endless series of iterations to a hopefully more general and accurate force. We mention this because, although the most drastic iterations are those we will find in the early testing periods, the process is one which never really ends.

There are two types of testing to which the model may be subjected. The first is an intuitive/subjective test using non-quantified but still empirical data. The second is formal validation. For sake of convenience, we shall call these "iterative testing" and "validation" respectively.

[8] Since this experimental evidence is clearly not eliciting production rules from experts, we will say no more about it. The literature describing such experimental procedures is extensive. It should be noticed that here as in many possible applications, it may be necessary to merge production rules with traditional scientific analysis.

<u>Iterative Testing</u>

Iterative testing must be used extensively in the development of the simulation. Once a set of production rules are developed for each class of production rules and the above described disagreements and inconsistencies are, at least, temporarily resolved, a set of the previously collected chronologies must be selected. These chronologies should permit inferences about the output of the class of production rules even though they may not provide explicit statements concerning them. For example, it can be expected that it will be difficult to find direct indicators of the detailed perceptions of changes in the external environment. However, the behavioral responses (both physical and verbal) will probably provide some indication of whether the production rules are consistent with observed behavior. It should be emphasized that the criteria for success will in nearly all circumstances be consistency rather than accuracy. *That is,* in most circumstances, it is unlikely that the chronologies will be sufficiently detailed to permit judgments of the proximity of the predictions of the observed events. The developer should, however, be able to make judgments that the results of the simulation are consistent or inconsistent with the observed historical events.

There is a question of who will be the judge of the consistency of the forecasts with the predictions. Ideally, the task should be performed by one or more informed critics who had not been involved in the preparation of the production rules. *This would avoid the problems attendant those who would* evaluate their own work. This may, however, entail a drain on already scarce resources. An acceptable alternative would be the use of the experts already

on the project. They could be requested to evaluate the production rules for which they personally were not responsible.

When inconsistencies appear, the first task should be to examine those production rules hesitantly rejected earlier. If one or more of these can be substitutes for those producing the errors, the substitution should be made and the results compared against the chronologies.

If there are no acceptable substitutes, or the substitutes do not remedy the situation, the experts will be asked to consider the reasons for the error and to revise the production rules to correct the mistake. The revision will then be tested against the original chronology to determine if the error has been corrected. If so, a new set of chronologies will be selected and the revised production rules will be tested against them. Again, they will be tested for consistency and if found inconsistent, the process will be repeated until a set exists which is consistent with a new set of chronologies.

Once this consistency is achieved, the experts and developer will proceed to the next lower run on the hierarchy of classes of production rules. The same procedure will be followed for this class as for the previous one. In fact, once the production rules are developed and the disagreements have been temporarily resolved, the same set of chronologies can sometimes be legitimately used to test the lower class as was used for the previous, higher order production rules. There is occasionally multiple information in any set of chronologies with inferences to the outputs of more than one class of pr's. Since the development of the classes of production rules is semi-independent, the <u>initial</u> testing would not be seriously biased by the reuse of the same data. Once any level of the hieararchy of production rules is satisfactorily tested independently, it should be linked to the previously tested higher level(s) and tested on a new

set of chronologies. If the combined set proves consistent with the data, the analysis may proceed to the next level of the hiearchy. If not, the developer and experts must retrace, recognizing that the errors may actually be generated as early as the first class of rules.

Validation

Throughout the process, the developer must bear in mind that he cannot proceed indefinitely on the intuitive impressions of the success of the simulation. During the developmental stages, the subjective evaluations were used because of measurement difficulties and the need to provide the substantive experts as rich (albeit more imprecise) an evaluation as possible. At some stage, however, it becomes necessary to sacrifice the substantive richness of these tests for the precision of a formal validation. This point occurs after all of the classes of production rules have been developed, linked and successfully tested subjectively.

The most difficult task is developing a set of output from the simulation which is comparable to the chronologies. This is done by carefully examining the chronologies to determine the state of the cognitive map at some initial point and then to set the cognitive map of the simulation as close to that as possible. From this point on, the user, playing the external environment, duplicates known history. If it works properly, the simulation will respond to these inputs in a manner very similar to that described in the chronologies.

The reader should notice that this differs from most tests of models of this sort because of the intervention of the user playing the outer environment. This constant pull back to known series of events reflects our belief that it is extraordinarily difficult to predict the interactive sequences of two or

more actors through any reasonably long sequence of activities. However, we believe that it should be possible to anticipate the reactions of one group of decision makers to unfolding of events as controlled by some outside group. As an example of this, we would not have much confidence in the ability to present a reliable scenario of U.S.-USSR behaviors across the next five years. However, a good model should be able to anticipate Soviet reactions if we assume a set of American actions.

The results of the general types of simulations which can be produced from the production rule methodology are particularly suitable to formal empirical validation. The output of the simulation is a chronology of perceptions and physical and verbal events hopefully resembling those observed in the real world. Just as chronologies from the real world can be coded and subjected to empirical investigation, *so can the output of the simulation.* That is, in fact, what should be done. Both the chronologies and the simulation should be coded according to identical coding rules such as those developed for the World Event Interaction Survey (WEIS)[9] or any other which is suited to the problem area being simulated.[10]

With two comparable sets of time series presumably describing behaviors of the same actors along identical measures, standard time series correlational analyses are appropriate. Since the time sequencing aspect of the simulation is

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[9] Charles McClelland.

[10] If extensive validation testing is anticipated, the developers might consider computerizing the output predictions of the simulation. Coding directly from the algorithm would probably not be particularly difficult.

one of its weakest points, the developer may wish to relax the point by point time series comparisons by aggregating to longer time periods. He may also be willing to test patterns of reactions across time rather than the specific point forecasts. For the first attempt, however, the straight forward point by point reaction to the actions of the external environment would appear the most powerful and easily explainable testing procedure. This could be accomplished either on a variable by variable basis using ordinary least squares (with a possible need to control for serial correlations) or on a total space by space basis using canonical analysis if an overall measure of the fit of the model is desired.

There also exists the possibility that if considerable data were available, probability density functions could be constructed for some of the major categories of inputs from the external environment. Estimates of these could be calculated both for the chronologies and the simulations. The probability density functions could then be compared against each other. This is an extremely powerful test, but it requires more extensive data than can normally be anticipated. Where that volume of data exists, it is normally gathered because of some abnormality, thus sharply limiting the generalizability of the results. The Pentagon Papers or the reports of the Arab-Israeli October War contain sufficient detail for such a test. There is some question, however, whether one would want to develop a simulation of such unique phenomena. There should be two formal tests: one on the combined set of chronologies used to develop the simulation and one on a remaining chronology which has been held in reserve by the developer. The test on the previously used chronologies should be made first. It is essentially the equivalent of the standard least squares tests. Here the developer is attempting to see how well his model fits the data used to generate the model in the first place. As with a complex regression

type model, he has a serious degree of freedom problem and cannot be particularly encouraged by positive results. Negative results, however, give him one last chance to make changes before he conducts the legitimate test against the new data.

The test against the new chronologies should be fairly definitive. Recognizing that a complex simulation permits an enormous number of permutations of events which will never be duplicated by any single set of data, an ability to produce satisfactory results against a reasonably representative set of data should give the simulation at least temporary credentials.

As we mentioned earlier, we do not really expect that any model developed in this manner will exist in its final, static, perfect state. Since the system can be built to interact with the user in a stylized form of English, the user sould be able to make continuous evaluations of unrealistic decisions made by the computer or of predictions which later proved to be incorrect. These types of weaknesses should be systematically recorded so that the developer or a knowledgeable group charged with maintaining the system can periodically revise or add needed production rules.

If, after its initial development, the simulation is taken seriously enough to be used, a conscious attempt should be made to systematically record the predictions made by the simulation and to subsequently compare them both in formal and informal tests against subsequent events. In this way, the process insures a continuous development of new, hopefully improved production rules.

<u>Conclusions</u>

In this report, we have sought to build on our experiences in developing production rules to help guide us and others who might wish to employ the production rule approach to develop simulations of social phenomena. As we mentioned at the outset, the primary work which has been done in this area so

far has been in the development of the logic and computer methodologies necessary to such ventures. The results of these endeavors have indicated rather clearly that computers can be made to interpret information, identify patterns, search alterantive responses and make decisions in a manner not too terribly different from the methods used by human beings. To date, however, it has been assumed that the developer of the simulation will be totally capable of supplying the information necessary to make it operate intelligently as a routine matter. That simply is not true. Most of the processes which are interesting to simulate are complex. Our knowledge, although extensive is not definitive and there are serious disagreements even among the most expert. Also the amount and type of information needed to complete the simulation rules out sole reliance on standard scientifically obtained information. As any who have attempted to use experts as information sources for quantitative analyses knows, the task is far from simple. The method we have suggested would seem to offer some promise.

The method is based on the following principles:

1) It must be as systematic and rigorous as traditional scientific analysis.

2) It must be developed within the context of a detailed structural framework.

3) It must be constructed such that the model is fit to known historical data.

4) Many portions of the simulation should be formally validated against known historical data after the developer is willing to accept the model as complete.

5) The experts will be asked to make their inputs in natural language sentences as causal sequences.

In essence, the method treats the intuitive information held by experts as alternative forms of data to be treated with the same care and respect as are received by the more traditional forms.

Although at such an early stage of development, it is nearly impossible to make any evaluation; we do have some ideas of the probable assets and weaknesses of the approach. The one major asset is the potential ability to incorporate the vast knowledge and logical abilities of human beings into scientific tools in a way never even approached by any of the existing systems. If researchers can succeed in tapping and harnessing that tremendous resource of information, there will, in all probability, be a major advance in the ability of social scientists to help the decision making community.

The system, even at this point, is not without its difficulties. Primarily it would consume enormous masses of a variety of resources. It has a high direct economic cost. The combination of computer programming, the time spent organizing the experts and interviewing them through multiple iterations, the time spent translating their causal sentences into production rules, the data collection and the validation tests constitute a significant outlay of dollars. The methodology also requires the nearly undivided attention of a number of experts through a period possibly as long as several months. Financial matters aside, it may be quite difficult to obtain that kind of commitment from very many busy experts. The computer requirements are also severe. The simulation which this project just produced consumed nearly 300,000 types of core storage, and this simulation was very limited in scope compared to what would be truly useful to a decision maker. This is a problem which may not be too limiting. Computer technology has already developed to the level where students and faculty members at MIT, University of Michigan and other schools with virtual memory systems have easy access to millions of types of core storage per user on standard runs.

The Pentagon now has such a computer available to the Air Force, PA&E and others. Furthermore, computer technology is developing more rapidly than is our model building capability. Still, the demands on the physical computer should not be ignored. The requirements will grow at an exponential rate with additional elements added to the system.

Finally, there are severe demands on both the information levels and on the data availability. The approach assumes that there exist experts who do in fact hold a great deal of intuitively obtained knowledge about the subject at hand. This may not always be the case. If our estimates of the knowledge of the experts is seriously deficient, the method will have the characteristics of the proverbial squeezing of bood from a turnip. Finally, one of the central elements of the methodology is its ability to permit the experts to go through an exercise much like fitting a model to data. This creates a critical need for the verbal chronologies. Where they are readily and extensively available, we can expect the model to function considerably better than in those instances in which the experts are limited to one or two iterations per class of production rule. In balance, the method would appear to promise a great deal. Unfortunately, like most things of considerable worth, the cost is rather high.

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